ZOOLOGY

A. M. WINCHESTER
H. B. LOVELL

SECOND EDITION

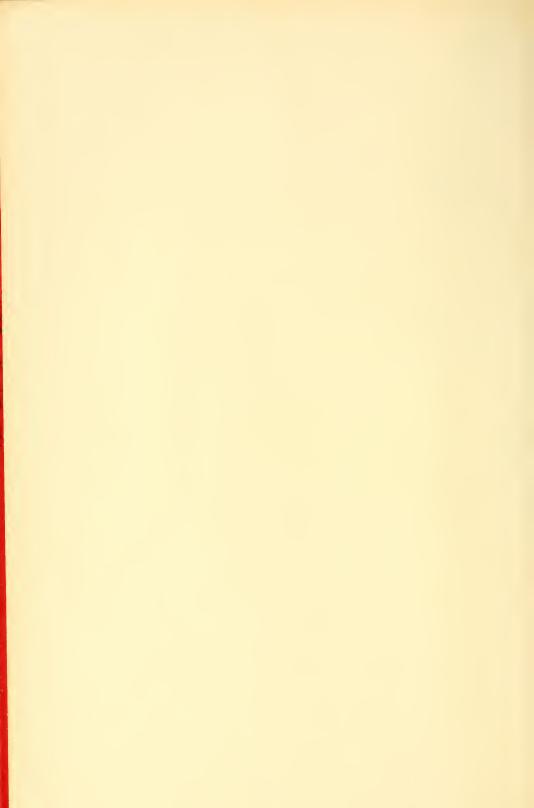# ZOOLOGY

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SECOND EDITION

Preface

This book has been written for the students, and every effort has been made to produce a volume which can be clearly understood, interesting, and informative. It is intended for a beginning course in zoology on the freshman level, but it is also adaptable to beginning courses in biology which may be taught with the concurrent use of a botany text.

Although the general plan of organization which proved so successful in the first edition has been retained, this edition represents more than a simple revision. New chapters have been included and much new material has been added to chapters carried over from the first edition. In accordance with modern zoological developments more space has been allotted to physiology both in the introductory chapters and in the survey of the animal kingdom. The sections on genetics and ecology have been expanded considerably in the light of increased emphasis on these subjects in beginning courses. In general the changes have been toward a book with somewhat more rigor, yet one that retains the clear-cut explanations and interest-stimulating references which have proved to make understanding easier.

Too often the interesting principles of zoology are ensnarled in the maze of technical words that have no more meaning for the beginning student than a foreign language. In order to avoid this pitfall the authors have used easy-to-understand language in the first part of the book and wherever a technical word, not in the vocabulary of the average college freshman, is first used it is explained thoroughly. In this way a vocabulary is gradually developed so that more scientific words can be used in later chapters.

This edition is marked by the addition of a junior co-author (Lovell) whose work as a critical reader has been valuable, who has rewritten many sections, and who is primarily responsible for Chapter 16 (The Honeybee), Chapter 29 (The Distribution of Animals), Chapter 30 (Ecology and Conservation), and Chapter 33 (The Development of the Individual).

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The Scope of Zoology

Students beginning a study of zoology often have vague and some-
times false impressions about the nature of this subject. It will be well,
therefore, for us to devote the first chapter to a consideration of the
scope of the subject of zoology so that those of you who are embarking
upon your first adventure in this field of science will have some con-
cept of what to expect along the way. Zoology is a study of those forms
of life which come under the broad heading of "animals." Many of you,
no doubt, have come to think of animals in a somewhat narrow sense—
you may think that the term is restricted to the fur-bearing animals
which have their young born alive. With this viewpoint you would
not think of a bird, a fish, or a grasshopper as an animal. In the
broader sense, however, animals include all of those forms of life which
are not plants (excepting a few microscopic forms which do not fall
readily into either classification). This is the sense in which the word
is used in its proper form. With such a broadened viewpoint you can
readily see that worms, snails, jellyfish, and human beings would all be
animals just the same as are cats, dogs, monkeys, cows, and hyenas.

The number of different kinds of animals which inhabit the earth
is very great. Something like a million different species of animals have
been studied, named, and described. Among these there is a great va-
riety—some animals are so small in size that they cannot be seen without
the aid of the microscope, whereas at the other extreme are animals
whose weight is measured in tons. Some of the smaller forms of ani-
mals have bodies that consist of single cells, while some of the larger
forms have literally billions of cells that are organized into complex
mechanisms of tissues and organs.

Since it is usually easier to proceed from the simple to the complex
in any field of study, we will take up the various forms of animal life
somewhat in the order of increasing complexity. The first animals we
will survey will be the one-celled forms in which all the vital life proc-
esses are concentrated into a single cell. By learning about the nature
and activities of these one-celled forms, you will be learning about life;
and the more you learn about life in any of its manifestations, the more
you will know about all forms of life. A knowledge of the functions of

digestion in an amoeba, for instance, will make you better able to understand this process in the human body when we come to that part of our study. If you will keep this in mind, the study of some of the simpler forms of life will be much more meaningful and valuable to you.

The Nature of Science

Zoology comes under that broad classification of learning which is known as science, and we will be better prepared for a study of zoology after we have learned something about the nature of science and its methods. It is often said that we are living in an age of science. Certainly there has never been a time in man's existence when his life has been so greatly influenced by science. As a matter of fact, the continuation of our present civilization on the face of the earth is dependent to a great extent upon our achievements in the field of science. With these facts in mind it certainly behooves all of us to know something about the nature of science and the way it develops.

Traditionally, science has been defined as an organized body of knowledge, and this definition is accurate as far as it goes. However, some critics have raised the objection that this implies that science is something static—as if all of the discoveries of science have already been made and it is our task only to organize this knowledge, utilize it as needed, and pass it to future generations. As a matter of fact, however, science is a dynamic thing—ever expanding as new discoveries pour in from research centers all over the world. It might be better, therefore, to expand our concept of science to include the process of investigation and discovery which is the active, dynamic phase of science. As these discoveries are made they must be organized and integrated with the great body of knowledge which already exists.

The Scientific Method

The process of scientific investigation or research is sometimes called the scientific method. Regardless of the topic under investigation, there are certain procedures that lead to an orderly, criticial method of study which will very likely lead to reliable results. This is the aim of scientific research—truth.

To begin with, there must be a realization of a **problem** before any investigation can be undertaken. Hence, we might consider a clear-cut statement of a problem as a beginning point for the scientific method. It is important that a problem be chosen that is rather narrow in range. An untrained investigator is very likely to select a problem which is so

complex and extensive that he could not begin to solve it in a lifetime of hard work. The simplest kinds of problems have a way of becoming difficult and complex when investigation starts; and, if there is to be any hope of success, it is well to be quite conservative when selecting a problem for study. As an example, an eager but untrained investigator might select the method of human inheritance as a problem. Hundreds of investigators working on many different phases of this problem for many years have not been able to get a complete solution. Hence, it would be much better to select a much smaller field of investigation. For instance, the method of inheritance of harelip in man would be a problem that would require extensive study, but with a good chance of a satisfactory solution. Even with this comparatively simple and narrow problem, however, there might be complex ramifications that would require years to untangle.

After a problem has been formulated, the next step in the scientific method is the formulation of an **hypothesis**. This is a postulation or a good guess as to a possible solution to the problem. It will be easier to find the correct solution if there is some possible explanation to test out in the investigations. In order to make a reasonable hypothesis, it is necessary for the investigator to survey all of the scientific literature in the field and to find out what has been done by others that might throw light on the problem. He may even find that someone else has already solved the problem and that he would have to select another problem. At any rate, he would save himself the time and trouble of repeating extensive investigations already done by others. In the case of inheritance of harelip, let us assume that the method of transmission of this defect has not been worked out definitely, but the information gathered on the subject indicates that harelip might be inherited as a dominant characteristic. Such a characteristic shows in persons who receive the hereditary factor for it from either parent. Accordingly, a hypothesis is formulated to the effect that harelip is inherited as a dominant characteristic.

Once a working hypothesis has been formulated, the scientist may then set himself to work to test the hypothesis against facts. **Observation** and **experimentation** may be used for this purpose. In some cases observation will be the primary method of investigation. For instance, in a study of the inheritance of harelip in man we would be limited to observation because we cannot conduct experiments in breeding human beings in order to determine methods of inheritance of certain characteristics. It would be possible, however, to study families in which harelip has occurred and to note the relationships of the afflicted persons. By tabulation and analysis of the results of a large number of such

studies, it might be possible to derive some conclusions as to the validity of the hypothesis which has been made.

In many scientific investigations, on the other hand, it is possible to control the subjects under investigation and thus to conduct experiments. For instance, if we wanted to learn about the method of inheritance of ear position in dogs, we could breed dogs with erect ears to those with drooping ears and, through a study of the ear position in the succeeding generations, we could hope to determine the validity of any hypothesis which had been made. Of course, observation and tabulation of results would be necessary where experimentation was used. In general, it is possible to obtain results faster where experimentation can be used in addition to observation than when we are limited to observation as the sole method of study.

When the data are analyzed it may be found that the hypothesis which has been formulated will have to be discarded and a new one proposed in its place, but the scientist must be very careful at this point not to jump to conclusions and to wait until conclusive evidence has been obtained before advancing any hypothesis to the status of a fact or even a theory.

Sometimes the word **theory** is used to describe an hypothesis which has accumulated a considerable weight of evidence behind it, but which has not reached the point of definite proof. There are some cases where it is impossible to obtain final, conclusive proof, and the statement must remain a theory indefinitely. Such scientific theories may be very valuable in the advancement of scientific knowledge. We should take care, however, to distinguish scientific theories from scientific facts, for they are sometimes confused in the popular mind. Take the subject of biological evolution, for example. Many phases of this subject are known facts that can be proved to the satisfaction of anyone who will take the trouble to investigate. On the other hand, there are theories as to the mechanism of evolution and the extent to which evolution has progressed in the past that have not been proved and can never be proved. We should distinguish between these in our thinking and not lump all statements about evolution into one category or the other.

The Scientific Method in Action

These statements about the scientific method may be better understood if we illustrate them with regard to an actual scientific problem. Suppose, for instance, that you wished to investigate a problem of mosquito reproduction—Is water necessary for the propagation of

mosquitoes? Since your previous observations indicate that mosquitoes do not reproduce without water, you might formulate the hypothesis that water is necessary for mosquito reproduction. A survey of the literature on the subject will give you a background of what has already been investigated. Let us assume that you find no conclusive evidence on the subject and, with the information you have, you plan your methods of attack.

You would probably decide to collect mosquitoes of different species and keep them in cages. In some of the cages you would place bowls of water and in the others there would be none. In the course of time you would notice that the mosquitoes in the cages having the water laid eggs in the water which later hatched into wigglers and finally came out as full grown mosquitoes. In the other cages there would be no reproduction. This would tend to support your hypothesis, but you would be careful not to jump to conclusions. You would want to study the mosquitoes in their natural environment to see if there might be something about your method of handling the mosquitoes in the laboratory that could have resulted in misleading findings. You might find mosquitoes living in an area where there were no apparent bodies of water in which to lay their eggs. How did they get there? You might have to conduct experiments on mosquito migration to see if they migrated from other regions. This might not explain the number of mosquitoes which you find. After much careful work you find that in some of the plants of the area rain water accumulates between the leaves and the stems. This water remains long enough to serve as a breeding place for the mosquitoes.

After many such investigations you may feel that you have conclusive proof that water is necessary for the reproduction of mosquitoes of the species which you have investigated and you could publish the information as a scientific fact. This would not prove that all mosquitoes need water, for there would be species in other localities which you have not been able to investigate. However, you might wish to propose a theory that all mosquitoes need water for reproduction, since your work indicates that this, in all probability, is true. This would be a very valuable theory to keep in mind in all work with mosquitoes even though we may never find it possible to investigate every species of mosquito on earth and prove the point conclusively.

The Controlled Experiment

The controlled experiment is one of the most important tools of the scientist. In most investigations it is necessary to conduct two

experiments simultaneously. These two should always be as nearly alike as possible in all details except for the one thing under investigation. For instance, in the mosquito experiment, if we are to feel reasonably sure that water is necessary for reproduction, all factors, except the presence and absence of water, must be exactly the same. Then, any differences which we observe can be assigned to the presence or absence of water.

A very good illustration of the value of such a controlled experiment was brought out in studies on poliomyelitis (infantile paralysis). Some years ago a serum was developed which gave promise of acting as a preventive for this dread disease. Experiments were devised to

Courtesy of E. R. Squibb and Sons

FIG. 1.1. The controlled experiment in vitamin research. These two rats were raised exactly alike except for the fact that the diet of the one on the left was deficient in vitamin A. Had it not been for a group of control rats, like the one on the right, who developed normal eyes, it would not have been possible to be certain that vitamin A deficiency caused the eye abnormalities of the experimental group, illustrated by the one on the left.

test the hypothesis that it would prevent the disease. During an epidemic year in a large New York clinic, parents who brought their children to be examined were asked if they would like to have this serum given to their children. The fact was made very clear to them that the treatment was still in the experimental stage and might not be of any benefit. About half of the parents decided to have their children inoculated. The other half felt that they did not want their children to serve as human "guinea pigs" and these were not inoculated. There

were thousands of children in each group; and, since they were taken at random, there was no reason to believe that there would be any over-all difference in the chance of exposure, nor of the initial susceptibility to the disease of the two groups. Those who received the inoculation were listed as the experimental group, and those who did not receive it served as the control group. Careful records were kept of the cases of this disease and the severity of these cases among the two groups. Much to the disappointment of all concerned, the doctors found at the end of the summer that there was no significant difference in the number of cases nor the severity of the attacks between the two groups. They were, therefore, forced to conclude that the serum was useless as a preventive of this disease. If this experiment had been made without the control group, the physicians would not have been certain that the serum did not have some value and might have gone on using it for years. With this evidence, however, they were motivated to continue research along new lines in their search for a preventive and to cease work with this serum.

This search proved fruitful, for within a few years another substance was found which gave promise of preventing the disease of polio. Again controlled experiments were arranged—this time during the height of an epidemic in Houston, Texas. Thousands of children were given the newly discovered substance (gamma globulin) which was obtained from the mixed blood plasma of many people. Thousands of others were given injections of plain water with a little salt in it. This second group served as a control. In this case the children who had taken the gamma globulin showed an almost complete absence of the disease for about five weeks, while the number of cases was rather high in the control group. With this information as a guide, additional work was carried out and the gamma globulin indeed did prove to be of value in short-term prevention of polio. At about this time, however, the Salk vaccine for polio was developed which promised a more lasting protection from the disease. Another extensive program of controlled experiments was undertaken involving hundreds of thousands of children in all parts of the country. These experiments show us the value and actual necessity of controls in any experimental investigations.

The Scientific Attitude

The scientific attitude is one of the most necessary yet hardest to achieve phases of scientific investigation. The scientific attitude involves an unbiased evaluation of the facts without influence by per-

sonal feelings. As human beings we all have feelings and emotions which too often influence our decisions. It is extremely difficult for us to ignore these personal factors and to use unprejudiced reasoning as a basis for our conclusions. The true scientist tries to realize that such prejudices exist and makes an earnest effort to make allowances for them in drawing his conclusions. Especially does he try to ferret out negative findings which run counter to his hypothesis. Failure to do this may prove quite embarrassing, to say the least. In the course of time, more careful investigators are almost certain to discover errors in conclusions when negative findings are not given proper weight. If we could learn to apply the scientific attitude to some of the decisions of our daily lives we would probably be much happier with the results of our decisions in future years.

The Practicality of Scientific Research

One sometimes hears criticism of scientific research being conducted in fields in which there seems to be no possible practical value in the findings. Such an attitude stamps one as being uninformed as to the methods of scientific progress. For one thing, any discovery which adds to the sum total of human knowledge is worth while. Just to discover and record something that no person has ever known before is a satisfying and worth-while achievement. To be sure, many scientific discoveries have turned out to be immensely practical, but in almost every case the scientist who made the discovery did not have a practical aim in mind while conducting the research. Hence, we can say that we have no way of knowing which investigations will result in practical ends and, therefore, that research must be continued in all fields in order to reap the practical results. The impracticality of research directed solely at practical ends has been proved in certain countries where the governments have tried to prescribe the direction of scientific research. The result has been a dearth of scientific findings of significance, practical or otherwise, and a dependence upon other nations for scientific advances.

A specific case might be mentioned to show how investigation in obscure, "impractical" fields may result in findings of great practical value. An American biologist, G. W. Kidder, has been studying the nutrition of a one-celled animal known only by its formidable-sounding scientific name of *Tetrahymena geleii*. Few people have even heard of this animal—it causes no disease—it is not of economic value—what possible good could come from a study of its nutrition? Let us see!

Kidder found that this one-celled protozoan required a substance known as guanine in its food in order to grow. He then tried substituting other substances chemically similar to guanine to see if the organism could grow on these. He found one substance, guanazolo, which *Tetrahymena* would absorb in preference to guanine, but it could not use this in its life processes. In other words, we might say that it had been tricked into taking a substitute food which it could not utilize properly and thus its growth was stopped completely.

Now what possible practical significance could such a discovery have? In higher animals there are sometimes certain cells of the body which grow wildly, out of control of the rest of the body. We know of such growths as cancer. Investigation showed that guanine was necessary for the growth of cancer tissue, but was not necessary for the growth of normal body cells. Experiments were then devised with mice that had cancers. Injection of guanazolo into these mice caused a complete inhibition of cancer growth, but did not harm the normal tissues of the bodies of these mice. Perhaps further investigation will show that this can also be used to inhibit cancer growth in human beings. If so, this will be a milestone in our fight against cancer— and all because a man wanted to find out about the nutrition of a one-celled animal.

Millions of dollars have been spent on directed research designed to find methods of relieving cancer, yet this one discovery which was not directed against cancer at all may have greater value than any of the other findings. Over and over again results similar to these have emphasized the impracticality of a narrowly planned program of scientific research. Science must always be free to investigate, without restrictions, any subjects which fall within the scope of its methods and to derive conclusions based on impartial findings or it will cease to be a science.

The Divisions of Science

When we use the word "science" without any descriptive adjective, we usually refer to the **natural sciences** which deal with natural phenomena in contrast to **social sciences,** such as sociology, which deal with human relations, or the **abstract sciences,** such as mathematics, which deal with abstract subjects. The natural sciences are further broken down into physical sciences and biological sciences. The **physical sciences** relate primarily with nonliving matter and include such subjects as physics, chemistry, geology, and astronomy. The **biological sciences** deal with living matter and include botany and zoology as major

subdivisions. Of course, there are many cases where these divisions merge, as in the study of biochemistry or biophysics.

The Nature of Life

Since our primary concern in this book will be with one of the biological sciences, it will be well to learn just what is meant by living matter. Offhand, you might think that there is little need for such a survey because the distinction may seem very simple. A cow grazing in the field is very definitely alive, and a rock on a mountain side is very definitely not alive. In tabulating some of the points of difference, however, we can better understand the nature of living matter.

1. Growth. Living matter has the unique distinction of growth. Whether it be a tree, a worm, or a man—all living things take food and convert it into a part of their bodies with a consequent increase in size. All forms of life start their existence as small, usually microscopic, bits of matter; yet by the process of growth through food conversion many of them are able to reach a very large size. Nonliving matter has no growth in a comparable manner.

There are some cases where nonliving matter appears to grow, but it is in an entirely different manner. When you visit a large underground cave you may see beautiful stalactites hanging from above and stalagmites coming up from below. These become larger with the passage of time by a special kind of growth. Water seeping down from above contains minerals in solution, and as this water runs down these formations some of the minerals are deposited to make the formations wider and longer. This method of increase in size is known as accretion and involves the addition of material to the surface. There are quite a number of examples of growth through accretion among nonliving material. You can readily understand, however, that this is entirely different from the growth of living organisms in which materials are incorporated from within.

2. Cellular Organization. Cells are small units of life which form the basis for the organization of most forms of living matter. Some forms are composed of single cells; and still others, such as viruses, do not have the complete cellular organization. However, with these exceptions, we can say that all living matter has a cellular organization.

3. Cell Respiration. All of the food which an animal takes into its body or which a plant manufactures does not go to increase the size of the body. Some of it is combined with oxygen for a consequent release of energy. This is known as cell respiration and through it an animal gets the energy necessary for its activities. It is possible to

combine food and oxygen to release energy outside of a living cell through the process of combustion, but this is a very rapid release of the energy as heat. In the cell the same amount of heat will be released, but it is released much more slowly—otherwise the cells would become overheated.

4. Response to Environment. All living things respond to their environment in a manner which is usually advantageous to themselves. This is sometimes known as irritability. The response may be quick

Photo by Winchester

Fig. 1.2. Mixed-up bird? It might appear as if the eyes of this owl have gotten mixed-up in their adaptations to light, but actually this is an excellent illustration of the short-term adaptations of living things. The picture was made by flash in a dark room while a flashlight was shining into the left eye of the owl. Thus, the left eye is adapted to a bright light, but the right eye is adjusted to the darkness of the room.

and fleeting or it may be longer in developing and longer persisting. If you touch a hot stove with your finger, your response is quick and definitely advantageous to yourself. This is a **short-term adaptation** to a temporary environmental condition—a quick stimulus-response reaction. If you go into a darkened room from bright sunlight you will temporarily be unable to see, but within several minutes the irises of your eyes will open up and admit more light. Plants turn their leaves in such a manner that they receive the best exposure to sunlight. Non-

living things, it is true, do show some response to their environment—a piece of steel placed in the sunlight will expand from the heat, but this response is purely mechanical and certainly could not be considered advantageous to the steel. It should be pointed out that responses of living things under certain circumstances may turn out to their disadvantage. A moth responds to bright objects by flying toward them. When these happen to be one of the many kinds of lights used by man, the results may be disastrous for the moth. This tendency of moths to fly toward bright objects probably has an advantage in a more natural environment. It probably leads them to the light colored petals of flowers at night where they may feed on the nectar, but this response becomes a disadvantage in the blaze of lights that man has created.

Long-term responses are slower in developing, but they last longer. For instance, if you are exposed to unaccustomed amounts of sunlight, you may be sunburned; but regular exposure over a period of time will cause the development of a heavier layer of pigment in the skin which will protect you from the burning rays. The tan will remain for some time after you have ceased to expose yourself. Mammals living in cold regions develop a heavier coat of fur than those of the same species that live in warm climates. Some people who raise mammals for their fur have found that those raised in a cold climate usually develop a heavier coat of fur than those of the same stock raised in a warmer climate.

5. Adaptation to Environment Through Natural Selection. All living things slowly achieve inherited adaptations to their environment which are passed from generation to generation. This is accomplished by the process known as natural selection. Living things tend to produce more offspring than can survive. There are differences among these offspring which are due to heredity; those best adapted to the environment will tend to have an advantage in survival over those not so well adapted. As a consequence, there is a selection for the hereditary factors which best fit the organisms for their environment.

As an example, the desert rat which inhabits dry regions of the western United States can live its entire lifetime without ever taking a drink of water and with dry seeds as its only food. As one of the adaptations to this environment it has developed a type of kidney which greatly concentrates the urine and thus loses little water from its body in this manner. This kidney is about four times as efficient as the human kidney in this respect. Such an adaptation probably came about through the selective elimination of those rats with less efficient kidneys—only those with the most efficient kidneys survived and transmitted this characteristic to their descendants.

There was a time when scientists had difficulty in trying to decide if viruses were living or nonliving. When it was discovered that they became adapted to varying environmental conditions through natural selection, it appeared that they should be included in the category of living things.

6. Reproduction. Since living things cannot continue to exist indefinitely as individuals, there must be some method of reproducing other living things like themselves or they will disappear from the face of the earth. In some primitive forms reproduction is very simple; after a period of growth each organism splits itself into two halves,

Photo by Winchester

FIG. 1.3. Find the bird. This is a photograph of a Poor Will's Widow on a nest of leaves. The fact that the bird blends so well with its surroundings is no chance occurrence. It is one of the inherited adaptations which comes about through natural selection. Only living things thus become adapted.

each of which becomes a complete organism; these grow and divide and the race thus continues its existence. Many plants and some simple animals produce buds, or similar outgrowths from their bodies, which grow into entire new plants or animals. The great majority of living things produce small sex cells which unite with cells from the opposite sex and initiate the life of a new organism.

It was once believed that living organisms appeared spontaneously from nonliving matter. Maggots were supposed to be generated by decaying meat; mice and rats were thought to originate from neglected garbage; and frogs were believed to appear from mud in the ponds

formed by spring rains. If you refer to books of past centuries you may find pictures of various stages of generation of eels from the mud at the bottom of a river, or there may be descriptions of how you can produce mice by mixing stale cheese, old rags, and other such ingredients. As science advanced, however, it became apparent that living organisms could arise only from pre-existing living organisms through one of the methods of reproduction described above. **Spontaneous generation** was accepted only because there was insufficient information about the method of reproduction of the forms of life involved. As more facts were revealed, all grounds for belief in spontaneous generation were dispelled. Even today, however, one will occasionally find a person who is not informed on the discoveries of science during the past century and who still holds to a belief in some form of spontaneous generation.

Plants and Animals

Zoology, we have already learned, is that branch of biology which deals with animal life. If you were shown a horse and a tree it would be easy enough for you to tell which was a plant and which was an animal, but there are some cases where the distinctions are not as easy, and some criteria are needed for differentiating them. Most plants possess that green material known as **chlorophyll**. We hear much about chlorophyll today because of its extensive use in personal products for human use. You might get the idea from some of the advertisements that the plants produce chlorophyll for the sole purpose of keeping human beings from smelling like human beings. The plants, however, have a much more practical use for this product—it is necessary for the very important process of food manufacture. Most plants do not get their food from outside sources and, therefore, must depend upon the chlorophyll to manufacture it within their own cells. However, plants known as fungi do not have chlorophyll and, therefore, must get their food from outside sources as do the animals. When we compare the structure of the cell wall and other features of the fungi with plants and animals, there is no doubt about their classification as plants. Also, there is good reason to believe that at least most of the fungi have descended from ancestors which bore chlorophyll, but have lost it in the process of their adaptation to a different way of life. There are a few simple forms of life which have some characteristics similar to animals, but which have chlorophyll like the plants. These are difficult to classify, but serve as excellent illustrations of the close similarity of the two in the lower levels of existence.

Branches of Zoology

We have now narrowed our consideration down to the subject of zoology, but we still find that this is a rather broad subject and, for purposes of convenience in study, it is broken down into smaller divisions. We will not attempt to list all of these, but there are some with which the beginning student of zoology should be familiar.

1. Morphology. This is the phase of zoology which deals with the structure of animals. It is further broken down into:

    a. Anatomy, which is gross structure or that which can be seen with the naked eye.

    b. Histology, which is microscopic structure or that which you can see when you put a small bit of animal tissue under the microscope for a detailed study. It is concerned primarily with the overall appearance of the cells and the materials which lie between the cells.

    c. Cytology, which is the detailed structure of cells. Microscopes must, of course, be used in this study as in histology, but cytology concentrates on the parts that go to make up an individual cell, how they operate in cell division, etc.

2. Physiology. This is the study of the functioning of the living animal. In other words, how the various parts of the body work to perform the vital life processes, such as circulation, digestion, etc.

3. Taxonomy. This phase of zoology deals with animal classification. There are many kinds of animals on the earth and they must be classified in some way. Similarities of morphological and physiological characteristics are usually used as a basis for the classification.

4. Genetics. This is the study of inheritance or the methods of heredity. It seeks to find the explanation for the similarities and differences that exist between parents and offspring.

5. Embryology. In this study, the development of the individual animal is traced from its earliest beginning. Since most animals originate from a single cell, that is where embryology starts. It continues through the divisions of this cell to the various parts of the body as they are formed and grow to form the adult type. Much of embryology is concerned with the structure of the embryo at various stages of its development; hence it might be considered as a branch of morphology, but in recent years there has been an increasing emphasis on the physiological features of embryology. In other words, in addition to learning how the embryo develops there is an attempt to learn what physiological reactions cause it to develop as it does.

6. Ecology. This is the study of an animal in relation to its environment. It includes such topics as: how the animal gets its food, what enemies it has, how it protects itself from these enemies, how it survives unfavorable climatic conditions, and many other complicated relationships of its natural environment.

7. Zoogeography. This is the study of animals as they are distributed over the face of the earth. It seeks to explain why animals are found where they are today, how they become dispersed by such agents as the Gulf Stream of the Atlantic, how barriers such as the Sahara desert of Africa hinder their dispersal. It is also concerned with those past geological conditions that may affect modern distribution.

8. Paleontology. This is the study of animals as they have existed in the past. The study must depend primarily on fossil records for its conclusions. Since there are such large numbers of these available, we have a fairly complete and accurate picture of prehistoric life, which is valuable in tracing origins of present-day animals.

In addition to these divisions, there are many subdivisions which are named for some particular group of animals. These include: **protozoology,** a study of one-celled animals; **helminthology,** a study of worms; **parasitology,** a study of animals that are parasites; **entomology,** a study of insects; **ichthyology,** a study of fish; **herpetology,** a study of amphibians and reptiles; and **ornithology,** a study of birds.

From this list you can see that zoology is a very broad and comprehensive study. In an introductory course in the subject it will be possible to give only a brief insight into these subdivisions. It is to be hoped, however, that your curiosity may be stimulated so that you will wish to know more about some of these branches and will study them further, either in formal courses or through your own initiative in self-directed study.

<div align="center">REVIEW QUESTIONS</div>

1. How does the dynamic concept of science differ from its definition as an organized body of facts?

2. What are the pitfalls which an untrained investigator is likely to encounter in the selection of a problem for scientific research?

3. Why should an investigator make a thorough survey of the literature on a problem before starting research on it?

4. What is the primary aim of scientific research?

5. Distinguish between observation and experimentation as tools for scientific research.

6. List some problem which would have to be solved primarily by observation and one that could utilize experimentation as a means of solution. (Do not list any mentioned in this chapter.)

7. How does a theory differ from a hypothesis; a fact?

8. Formulate some zoological problem and tell how you would go about solving it. (Do not choose one mentioned in this chapter.)

9. Why are controlled experiments so important in scientific research?

10. Name some personal problem which might face a college student of today and show how the scientific attitude could be of value in solving this problem.

11. Why are negative findings so important in scientific research?

12. Why do we say that scientific research aimed solely at practical ends is the most impractical scientific research?

13. How does the growth of nonliving things differ from the growth of living things?

14. How does the response to environment of nonliving matter differ from the response of living matter?

15. Name three short-term and three long-term responses to environment of animals not mentioned in this chapter.

16. Give an example of adaptation to environment of some species of animal and tell how such adaptation might have come about.

17. What is the major difference between plants and animals?

18. Distinguish between the three subdivisions of morphology.

19. Give the phase of zoology that would be primarily involved in the following studies: a. Nesting habits of flamingos. b. Inheritance of eye color in man. c. Ancestry of modern horses through fossils. d. The development of a chicken within the egg. e. The cause of blood clotting. f. The distribution of rattlesnakes in the United States. g. The structure of the human kidney.

20. After your study of this chapter do you feel that you have a fair insight into the nature of the subject of zoology? If not, list the topics discussed which are still not clear in your mind or topics which you think should have been included but were not.

2

The Cell as a Fundamental Unit of Life

Today it is generally understood that cells are the basic units of living matter, but such a concept has come into general acceptance only in comparatively recent times. Before the days of the modern microscopes it was thought that all living things were individual units in themselves without any subdivision into smaller parts. Then, as the primitive microscopes were developed, it gradually became apparent that there were smaller units of organization, in some forms of life at least. To Robert Hooke, an English biologist, goes the credit for early observation and naming of cells. In 1665 he published a book describing the compartmentalized nature of many different forms of living matter he had observed. In particular he described this structure as seen in thin slices of cork. The compartments which he saw reminded him of the cells of a honeycomb in a beehive and he, therefore, suggested that they be called "cells." Of course, he saw only the dry, dead cell walls in the cork, for all of the protoplasm had died and was dried up, but the suggested name received general acceptance and we use it today.

In the course of time the nature of cells became better known; and finally, in 1839, two German biologists, Schleiden and Schwann, after thorough research on both plant and animal material, formulated the cell theory, which held that all living things are composed of cells. Continued study has shown this theory to be essentially correct, although we now know that there are certain very elementary forms of life, such as viruses, that must be excepted from such broad generalizations. Much biological research today is concentrated on the cell, for we realize that the key to many of our complex problems of heredity, growth, reproduction, embryology, and physiology lies within the cell. Before beginning a study of the animals as a whole, therefore, we will spend some time learning something about this smallest unit of animal organization, the cell.

The Parts of a Cell

If you wish to see some cells from the human body you can obtain them easily by gently scraping the skin on the inside of your cheek

(inside your mouth). This will loosen some of the cells of this region which can then be mounted in a little water and placed under the microscope. When viewing such cells you may get the impression that a cell is a very simple thing. There will be a clearly defined outer surface which is known as the **cell membrane,** inside there will be a spherical **nucleus,** and in between there will be a clear material called the **cytoplasm.** The cell has many other parts, however, which this study does not reveal. To see these it is necessary to use some method that will give us a greater contrast between the various components of the cell. We can achieve such contrast in living cells by using a

Golgi bodies
Centrosome
Nucleus
Chromatin
Nucleolus
Nuclear membrane
Cytoplasm
Vacuole
Mitochondria
Plasma membrane
Cell membrane
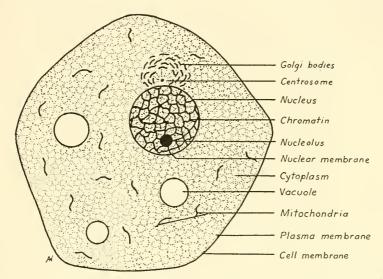
FIG. 2.1. A typical animal cell. Diagram of the parts of a typical animal cell that can be brought out by various microscopic techniques.

phase contrast microscope which transforms slight differences in the refractive index of the parts of the cell into visible differences in contrast. For a still more detailed study we can apply special stains to the cells. Cell components differ in chemical structure and hence differ in their reaction to various stains. Some parts absorb one stain readily, but repel other stains. By using several stains it is possible to get a varicolored image which brings out fine details of cell structure. We will describe some of the parts of the cell which can be seen by such techniques.

The outer surface of the living part of the cell is known as the **plasma membrane.** This very thin membrane, which lies just under the cell membrane, serves to hold the contents of the cell and to

regulate the passage of materials into and out of the cell. In most plant cells there is a **cell wall** outside the plasma membrane, but this is commonly lacking in animal cells. This wall is secreted by the cell, but is not considered to be a living part of the cell. It is always quite porous in comparison with the plasma membrane and does not interfere with the movement of materials into or out of the cell. The **cytoplasm** which lies between the plasma membrane and the nucleus is a viscid fluid somewhat like the white of an egg and contains numerous bodies suspended in it. There will be **vacuoles,** which appear as bubbles, that usually contain water together with dissolved salts and
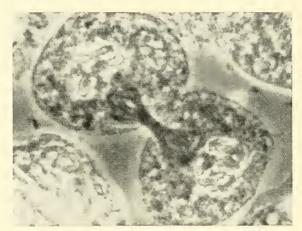
Photo by Winchester

FIG. 2.2. Mitochondria. In this living grasshopper cell which has almost completed division, the mitochondria can be seen as a bundle of rod-like bodies which is the last part of the cell to divide.

food materials. Scattered through the cytoplasm there are also **mito-chondria,** which usually appear as rod-like or thread-like bodies which recent research has shown to be centers of enzymes that play such an important part in the physiology of the cell. These enzymes stimulate chemical changes which are a part of the normal functioning of a cell. Each enzyme is specific in its reaction, so there must be as many enzymes as there are needed reactions.

In most animal cells and in a few plant cells there is a **centrosome** which may be seen near the nucleus. This appears as a central body (sometimes it is a double body) surrounded by an area of cytoplasm which is different in appearance from the rest of the cytoplasm. In animal cells only there will be **Golgi bodies** which are usually collected in an irregular mass near the centrosome. The function of these is not

definitely known, but it is thought that they are associated with secretions of the cells. Most plant cells, but few animal cells, contain **plastids** which are bodies concerned with constructing substances within the cell. Some of these plastids (chloroplasts) contain the vital chlorophyll which manufactures food; others are centers which convert simple sugar into starch.

The **nucleus** of a cell usually appears as a large spherical body separated from the cytoplasm by a nuclear membrane. Within the nucleus there is an irregular network of thread-like bodies which is commonly called the **chromatin network.** The individual thread-like bodies are known as **chromosomes**—these become very distinct as they become shorter and thicker during various phases of cell reproduction. The chromosomes contain many very tiny bodies, known as **genes,** which are the units of heredity. Much remains to be learned about the method of gene action, but we have discovered that at least some of the genes produce their results through enzymes which they produce or which they cause to be produced within the cell. There also may be one or more **nucleoli** within the nucleus. These appear as spherical bodies associated with the chromosomes.

All of the living parts of the cell including nucleus and cytoplasm come under the general heading of **protoplasm.**

Cell Metabolism

Metabolism is a word that refers to the sum of the various chemical activities which provide for the growth, repair, and energy release of protoplasm. It is commonly divided into two categories—**anabolism** which involves the building of protoplasm from the raw materials coming into the cell, and **catabolism** in which there is a breakdown of the materials within the cell with a release of energy. In a reducing diet an effort is made to reduce the intake of food to a point where the forces of catabolism will exceed those of anabolism, and some of the stored food in the body will be used to supply the extra energy. Unfortunately, the balance between anabolism and catabolism varies in different persons, and it is much more difficult to maintain a proper body weight when either of these forces tends to overbalance the other. Many of you have probably had a basal metabolism test made to determine your rate of catabolism when you are in a state of relaxation. This is done by measuring the amount of oxygen which you consume during a given period of time. Since catabolism uses oxygen in the release of energy, this gives an indication of the rate of the

catabolic phase of metabolism. Certain hormones can be used to speed the rate of metabolism when it is too low.

The cell is the unit in which metabolism occurs. Whether plant or animal, it is in the cell that food is altered chemically by the **enzymes** of the cell with the resulting formation of living protoplasm. These enzymes function as catalysts, which means that they stimulate a reaction to take place without being used up in the reaction themselves. When we study the many chemical changes that take place within a cell, we can but marvel at the many enzymes which must be present to accomplish all these changes. All cells require a certain amount of energy release in order to continue living, so catabolism must take place to a certain degree at all times. In dormant seeds, or in animals which are in a dormant state such as hibernation, the rate of catabolism may be reduced to a very low level. If the spark of life is to remain, however, it must take place. Again, it is the enzymes within the cell which cause the breakdown of the substances that have been built up by anabolism and the ultimate release of energy from these substances through a combination with oxygen.

Metabolism is the force of life itself.

Two Cells from One

Of all the fascinating properties of life there is none more remarkable than the ability of living matter to generate additional living matter like itself. To illustrate, let us consider an amoeba crawling along in the debris at the bottom of a pond of water. The amoeba is a microscopic water animal whose entire body consists of only one cell. This one cell carries on all of the processes necessary for the continuation of life. It takes in food and oxygen, throws off waste matter, and responds to its environment, as is true of larger forms of animal life with many cells in their bodies. Some of the food taken into the body, however, is converted into additional protoplasm within the cell. Thus, the amoeba grows in size—it becomes larger, but such enlargement cannot continue indefinitely. Eventually it would become so large that there could not be sufficient exchanges of material through its plasma membrane to maintain life and it would die as a result. Something happens, however, to prevent this tragedy.

The amoeba ceases its normal movements and certain internal changes become apparent. Small, rod-like bodies (chromosomes) appear in the nucleus—these line up in a row and separate into two groups, each of which forms the center for a new nucleus. Then a constriction develops which separates the cell into two equal parts each

of which contains one of the new nuclei. We commonly say that the amoeba has divided, but it has not divided in the sense that an apple is divided when it is cut into two equal parts. These are not two half-cells—these are two entire cells. Hence, it would be more accurate to think of this process as cell duplication rather than cell division. It is true that each of the cells formed will be only about one half as large as the original cell, but each of these will be a complete organism bearing all of the potentialities of the original amoeba. Through growth each of these organisms can attain the size of the original, for each has all of the important units of heredity possessed by the original one. Each of these will in turn duplicate itself in the manner just described unless some misfortune should intervene.

For the amoeba, cell duplication is always reproduction, for two animals result whenever a cell is duplicated. For the animals with many cells in their bodies, cell duplication becomes a vital part of body growth as well as reproduction. Each of us, as a human being, began life as a single cell. It has been through the process of repeated cell duplication that the billions of cells which now form your body have been produced. Furthermore, the process continues in your body throughout life to replace certain injured and worn-out body tissues. Your skin is constantly being shed from the surface and being replaced by new cells which are formed beneath. Billions of new blood cells are poured into your blood stream each day to replace those which wear out in their daily duties or which may be lost by bleeding. When the time comes for reproduction, again this process furnishes a plentiful supply of cells which can be used to produce new individuals. Thus it becomes apparent that cell duplication is an extremely important part of the life of any animal that exists.

The Process of Mitosis

The normal process by means of which cells become duplicated is known as mitosis. The most spectacular phase of this process consists of the splitting of the cell into two parts, but this represents the finale— the climax of an extensive series of prepatory events which insures the production of two complete cells by this splitting. To get at the beginning of mitosis let us first consider those submicroscopic units of heredity known as genes. These tiny units are found within the nucleus of cells. They are the directors of the activities within the cell as well as supervisors of the final role which the cell shall assume in the formation of a body. For instance, if you have brown eyes, curly hair, or even great aptitude in music, it is because your cells contain genes which give

you these characteristics. There are so many functions to be performed by the genes that there must be a very large number of them—a recent estimate puts this number at about 20,000 for each human body cell. Yet, if cell division is to be true cell duplication, each of these
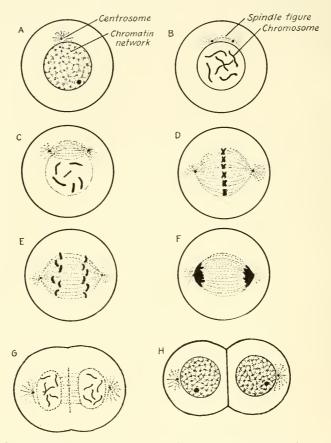
FIG. 2.3. Mitosis in a typical animal cell. These diagrams show the stages of cell duplication as seen in the usual stained specimens. A. Interphase. B. Early prophase. C. Late prophase. D. Metaphase. E. Anaphase. F. Early telophase. G. Late telophase. H. Daughter cells.
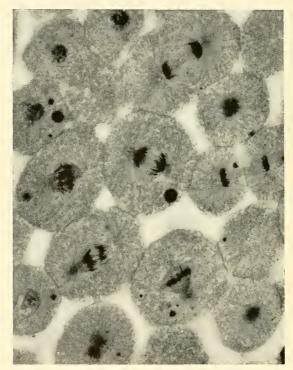
genes must first become duplicated and one of each kind of gene passed to each of the new cells formed.

Such a process appears to be a major engineering undertaking on the part of the cell, and it certainly is; but it is greatly simplified by the method of gene arrangement within the nucleus. The genes are not indiscriminately scattered throughout the nucleus, but are arranged

in a linear order on long slender strings known as **chromosomes.** These chromosomes form a mass known as the chromatin network which can be seen in cells which are not in some stage of mitosis. In a typical body cell of man there are 48 of these chromosomes, so there will be an average of about 400 genes to each chromosome. It is quite evident from this discussion that genes must be extremely small in size—so small, in fact, that they cannot be seen by ordinary microscopic methods. Through various techniques, however, it has been established that genes are probably very large molecules made up of nucleic acid combined with protein to form nucleoprotein. Genes have the remarkable power to take the materials absorbed by the cells as food and convert them into other genes like themselves. Genes normally perform this duplication only once for each cell division, so that the number of genes remains constant throughout repeated cell divisions. This gene duplication, then, is the beginning point for a study of cell duplication. For purposes of convenience of study, the process of mitosis is usually divided into distinct stages or phases which we will consider at this time.

Interphase. This is not actually a phase of mitosis, but a stage in between mitoses. It is sometimes called the resting stage, but the cell is resting only with respect to mitosis. It may actually be at its peak of metabolism and growing rapidly. In typical cells at this stage the chromosomes are extended to their greatest length and are often so thin that they are not easily visible. Instead they may appear as a diffuse chromatin network within the nucleus.

Prophase, the phase of preparation. Typical cell duplication begins with the duplication of the genes together with the threads upon which they lie. Each chromosome is now in reality a double thread of genes, but they adhere closely together and their dual nature is not readily apparent in all cells. Each chromosome bears a body somewhere along its length known as a **centromere** which is to play an important part in mitosis. The centromeres do not become double when the genes become duplicated, and thus each double gene string has only one centromere at this stage. Next, the chromosomes gradually become shorter and thicker so that they become clearly visible within the nucleus. This shortening and thickening is accomplished by a coiling of the chromosomes followed by a deposition of a matrix around the coils as shown in Fig. 2.5. The matrix may obscure the coiled nature of the strings of genes within the chromosome. It is often possible to see the dual nature of the chromosomes, however. Each half of a chromosome is known as a **chromatid.**

In the meantime, the nuclear membrane fades from view and the chromosomes appear to be free in the cytoplasm. The **centrosome,** if present, is forming the spindle figure which is to function in the division of the chromosomes. The two little dot-like **centrioles** within the centrosome begin to spread apart and spindle fibers appear between them to form the **spindle figure.** Delicate microdissection studies in

Courtesy General Biological Supply House

Fig. 2.4.   Photo of mitosis in the eggs of the whitefish. A resting cell, prophase, metaphase, and telophase can be seen in this group.

which extremely tiny needles are inserted into the cell indicate that these are not true fibers, but instead represent lines of force within the protoplasm. It has been suggested that the fiber-like appearance is due to the lengthwise orientation of molecules in these lines of force. As the spindle figure becomes larger it spreads down over the center of the cell and engulfs the chromosomes. The chromosomes then become arranged in the form of a disc within the center of the spindle at the end of the prophase.

Metaphase, the phase of separation. The metaphase begins as the chromosomes reach the center of the spindle. It can be seen at this point that a spindle fiber is attached to each centromere of the chromosomes. Next, the centromeres divide so that there is one for each of the coiled gene strings or chromatids. The spindle fibers now seem to exert a pull on these centromeres, and they are pulled along to the poles at each end of the spindle dragging their chromatids behind them.
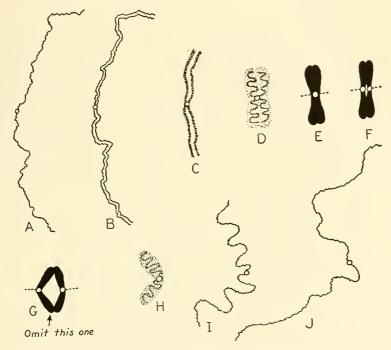
FIG. 2.5. The life cycle of a single chromosome. Starting with the chromosome in interphase (A), we see how it becomes duplicated and then shortens by coiling (C and D). After separation at metaphase (G), the chromosome uncoils as it goes into another interphase (J).

Thus, the actual splitting of the chromosomes is accomplished; although, as we have seen, it was preceded by a duplication of the genes and the gene strings some time earlier. As a chromosome is thus separated, each chromatid now becomes a separate chromosome. It is no longer a half-chromosome, but a complete chromosome in itself.

Anaphase, the phase of migration. After the chromosomes have been pulled apart to form two distinct groups, the cell is said to be in the anaphase. In this stage each centromere leads the way with the balance of the chromosome being dragged along behind. This causes

the chromosomes at this stage to assume characteristic configurations. If the centromere is attached in the center, the chromosome will be V-shaped; if attached between the center and the end, it will have a J-shape; if attached at or very near the end, it will appear as a straight rod.

Telophase, the phase of reconstruction. When the chromosomes reach the poles of the spindle they form a rather tight aggregation and the cell is said to be at the beginning of the telophase. In many respects this stage is an exact reverse of the prophase. The chromosomes become longer and thinner as they become uncoiled and lose the matrix, the spindle figure disappears, and the nuclear membrane reappears. During these changes a **cleavage furrow** develops which gradually pinches the cell into two parts and the process of mitosis is complete.
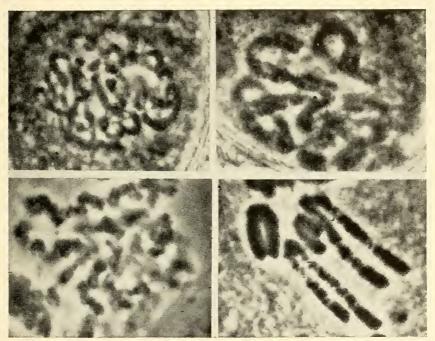
Daughter Cells. We now have two cells which are in the interphase again—cells which are identical and are usually known as daughter cells at this time. The entire process of mitosis which we have described consumes only about one hour as a rule. In so short a time there can be little opportunity for cell growth, so that each of the two cells which has been formed is only about one half the size of the original cell. Yet—to emphasize it again—each of these cells has the same number and kinds of genes as were present in the original, thanks to the precision of the process of mitosis. This fact can be demonstrated in a rather dramatic manner. If the original cell happened to be a fertilized egg from which an animal, let us say a salamander, will develop, then each of the daughter cells will normally go on to produce one half of the body of the salamander. It is possible, however, to separate the two cells experimentally, and then each cell will usually form an entire salamander which will be no different from a salamander which was formed from an unseparated fertilized egg. Furthermore, these two salamanders will bear identical genes and will, therefore, show identical hereditary characteristics. The same thing may be demonstrated in human beings. Normally, a single fertilized egg will produce a single individual, but at times the early embryo may become split into two parts and each part will go on to produce a complete individual. This results in what we call **identical twins** because they have identical genes and will always look very much alike. We should point out, however, that there is another type of twins, the **fraternal twins,** which originate as two fertilized eggs to begin with. They are no more alike than brothers and sisters born at different times and may be of different sexes.

The process of mitosis is somewhat complex, but it is a very efficient method of cell reproduction. It is the method by means of

which cells are duplicated in practically all forms of life. Since it is so universal and so important a part of life it will be well to learn it thoroughly before proceding on to a further study of animal life.

Regulation of Mitosis

What controls the rate of mitosis—why do cells sometimes become duplicated rapidly when there is need for new cells and then cease

Photos by Winchester

FIG. 2.6. Photographic evidence of coiling of chromosomes in living plant and animal tissue. Top left, prophase of Tradescantia (Spiderwort) showing coils. Top right, later prophase of same plant showing the two complete sets of coils of the duplicated chromosomes. Lower left, prophase from a cell of the grasshopper testes; the double coiling system can be seen in some places. Lower right, several chromosomes from an anaphase of the same insect in which the chromosomes have been pulled out to show the coils.

their duplication when this need is satisfied? In the answer to this question lies the solution to many problems of biology. During the early stages of the development of the human embryo the cells may undergo mitosis every twelve hours or so. When the body is mature, however, most of the cells cease duplication, as there is no longer

need for more tissue. Some cells, such as those of the brain and nerves, never undergo mitosis again. Other cells, such as those of the bones, do not reproduce unless there is an injury, in which case they will produce new cells until the injury is repaired and then they cease reproduction. Still others, such as those of the skin and the blood-producing cells, continue mitosis throughout life and thus replace the skin cells and the blood cells which are destroyed in the course of our daily living. If an injury should destroy some of the skin, the rate of mitosis in the surrounding skin cells will become increased until the damage is repaired; then the rate will be reduced to normal. The same is true of the blood-producing cells when there has been extensive loss of blood through bleeding. In other words, there seems to be some force which stimulates cells to undergo mitosis when new ones are needed and prevents mitosis when there is no need for new cells.

An explanation of the method of regulation of mitosis is of vital interest, for here may lie the clue to the solution of one of the greatest medical problems of our times—cancer. This dread affliction, which so often turns a person's later years into a nightmare of pain and suffering, is becoming more prevalent as the human life span is increased. In cancer the factor which causes mitosis to cease when there is no need for new cells is somehow lacking and there is a rapid, uncontrolled rate of cell reproduction. This forms a mass of tissue which is outlaw tissue—cells growing wild—cells out of control—cells which are parasites on the body of which they were once a normal part. Up to the present time the most effective way to stop these mitoses and kill the cells has been through the use of x-rays and radium. However, much of the cancer research today is directed at an effort to find the factor which regulates mitosis. The increased rate of cell duplication which follows injury seems to be due to wound hormones produced by the injured and dead cells. This has been demonstrated in plant tissues and is thought to be true of animal tissues also. Also certain chemicals have been discovered which stimulate or inhibit mitosis in experimental tissue. If some method is found to apply mitosis-inhibiting chemicals to cancer tissue or to apply chemicals which will neutralize the mitosis-stimulating substance, we might be near a solution to the cancer problem.

A Problem of Chromosome Number

The number of chromosomes found in the cells of plants and animals is constant among all members of the same species. There will be variations in the genes in the chromosomes which account for the

individual differences of the different members of the same species, but the total chromosome number will be the same. There may be considerable variation in the chromosome number, however, among members of different species. For instance, a domestic chicken has 18 chromosomes in its body cells, a dog has 22, a bullfrog has 26, a fruit fly has 8, and man has 48.

The fertilized egg (zygote) which produces a person contains 48 chromosomes; after this cell is duplicated each of the two cells formed
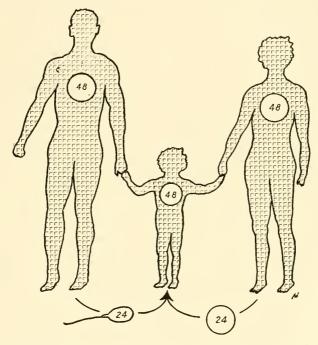
FIG. 2.7. How the problem of chromosome number is solved. Although human body cells typically have 48 chromosomes, this number is reduced to one-half (24) when the reproductive cells are formed. When these unite and produce a new life, the full 48 chromosome number is restored. Thus, the number remains constant for the species from generation to generation.

will contain 48 chromosomes, thanks to the exactness of mitosis. Through continuing mitosis, this chromosome number is held constant so that the cells of the brain, skin, stomach, liver, and other body organs each will contain the same 48 chromosomes. When the time comes for reproduction, however, an important problem arises. A new human life is produced by a union of two cells (the sperm and the egg) from two different persons. If both of these cells contained 48 chromosomes
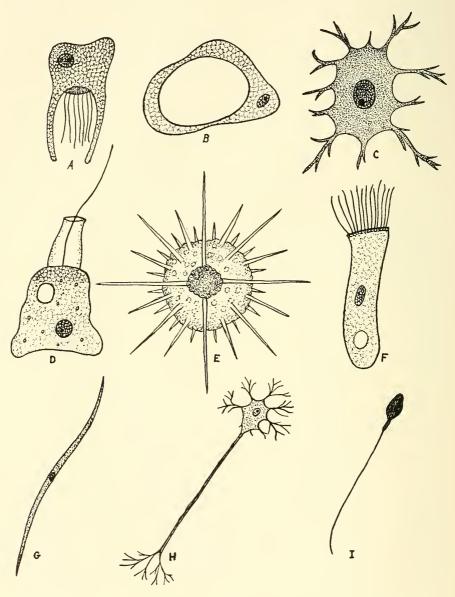
Fig. 2.8. Variation in animal cells. As cells become specialized to perform specific duties they show many variations in shape. A, a flame cell from the excretory system of a primitive worm; B, a fat cell from human tissue; C, a pigment cell from the skin of a frog; D, a collar cell from inside a sponge; E, a one-celled animal closely related to an amoeba; F, a cell from ciliated epithelium in the intestine of a clam; G, a smooth muscle cell from the stomach of man; H, a human brain cell; I, a human sperm cell.

then the child which was formed would have double this number (96) in each of the body cells. The following generation would have double this number and so on, until an impossible number of chromosomes would be obtained. Hence, it is readily apparent that something must intervene to hold the chromosome number constant from generation to generation. This is done by a reduction of the chromosome number to one half in the reproductive cells. The human sperm and the human egg each contain only 24 chromosomes instead of the 48. A special type of cell division, known as **meiosis,** takes place shortly before the sperms and eggs are formed and accomplishes this reduction. Meiosis is true cell division rather than cell duplication, because both the cytoplasm and the chromosomes are divided into two equal parts in this process. The chromosomes line up in pairs at the metaphase and 24 of them move to each pole of the spindle before the cell divides. In ordinary mitosis, on the other hand, you will recall that the chromosomes line up in a row in the center of the spindle, are split to form 96, and 48 move to each end of the spindle. This is the basic difference between the two—in mitosis there is chromosome duplication followed by cell division; in meiosis there is separation of pairs of the chromosomes without duplication, followed by cell division. Thus the chromosome number remains constant from generation to generation with each parent contributing one half of the chromosomes which go to form the gene complex of a new life. In a later chapter (Chapter 31) we shall learn more about the details of meiosis in the actual formation of the sperms and the eggs.

REVIEW QUESTIONS

1. Tell how and by whom cells were discovered and named.
2. Why do cells show a varicolored image when they are treated with several different kinds of stains?
3. List the parts of a typical animal cell and the functions of each that were given in this chapter.
4. Distinguish between anabolism and catabolism.
5. What is the relation between growth and cell duplication?
6. Explain how the duplication and separation of genes are facilitated.
7. Describe the events which take place in each phase of mitosis.
8. Why are the chromosomes of different shapes during the anaphase?
9. How do identical twins prove the duplication of genes in mitosis?
10. Why are identical twins more alike than fraternal twins?
11. What is the relation of research on mitosis to cancer control?
12. How is the species number kept constant in a species from generation to generation?

3

The Chemistry of Life

All living matter in the universe has a chemical structure. To understand living matter more fully it is best to learn something about its chemical nature. All living matter is composed of one basic material, protoplasm, which has some similarities in all forms of life. Hence, when we learn about the chemical nature of protoplasm in one form of life we have some understanding of the chemical structure of protoplasm in other forms of life. The name protoplasm was first suggested in 1840 by a Czech scientist, Purkinje, when he observed this viscid fluid in a wide variety of different kinds of cells. The cells may produce a great variety of products that exist around the protoplasm or as inclusions within the protoplasm, but the actual living part of the cell remains the basic protoplasm. We might expect this protoplasm to consist of chemical elements which are entirely different from those which form the nonliving materials of the universe, but this is not true. Some of the most common and widely distributed elements of nature, such as carbon, hydrogen, oxygen, and nitrogen, are used in the construction of living matter.

The Nature of Matter

Before we can understand the chemical nature of protoplasm we must review a few simple facts of elementary chemistry as a background. Let us start with matter. **Matter** is anything that has weight and occupies space. It may exist in any one of three states—**gas, liquid,** or **solid**—and it may change from one to the other under different conditions of temperature or pressure. Water is an example of matter which readily changes its state. Water is a liquid when the air around it is at the pressure found at sea level and its temperature lies between 32°F. and 212°F. Below this range of temperature it forms ice and is a solid. Above this range it forms a gas known as steam. Regardless of the state in which it exists, however, water always has the same chemical composition (H_2O.)

The state in which matter exists depends upon the speed of movement of the molecules which compose it. Molecules are in motion in

all states of matter, but may vary in their speed of motion and in their position with relation to other molecules around them. In a solid the molecules vibrate back and forth, but remain in fixed positions. In a liquid they move faster and are free to move about one another. This gives the fluidity to a liquid. In a gas the molecules attain a very high speed, a speed so fast that the molecules separate from one another and become independent free-floating bodies. The movement of mole-

Other minerals 4%
Nitrogen 3%
Hydrogen 10%
Carbon 18%
Oxygen 65%
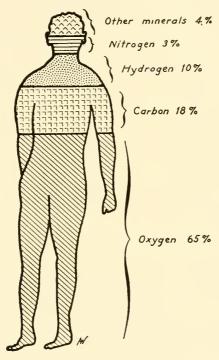
Fig. 3.1. Proportion of the different chemical elements in the human body by weight. Note that oxygen, carbon, and hydrogen make up 93 per cent of the body weight.

cules is dependent upon the energy of heat, and the higher the temperature the faster the movement. This explains why temperature changes cause changes in the states of matter. There is always some molecular movement, however, even in heavy solids. This movement would stop if the temperature ever reached absolute zero (minus 273°C. or minus 460°F.). This temperature has never yet been obtained, although scientists have come within a fraction of a degree of it. This gives us a lower limit of temperature, but there seems to be no upper limit. We have special ovens that produce temperatures of several thousand de-

grees centigrade. The center of a hydrogen bomb at the time of explosion reaches a temperature up in the millions of degrees.

All of this movement of molecules may seem fantastic, but it can be demonstrated rather easily in the zoology laboratory. If we suspend any very small particles—bacteria, fine soil, etc.—in water and view them under the high power of the microscope, these particles will be seen to move. They move back and forth rapidly in different directions. Such movement is known as Brownian movement. Where does the energy of such movements come from? It is the movement of the molecules of water which bombard these small particles on all sides. The molecules are much too small to be seen, but as they hit the suspended particles with great force they can cause movement of the particles. It is probably not a single molecular hit which causes movement in any direction, but a brief unbalance of hits from different sides. If more molecules hit the particle from one side than another, then the particle will be driven away from the side of greatest hits. We can often see Brownian movement of small particles inside of living cells when viewed under the microscope.

Divisions of Matter

All of the matter of the universe may be divided into elements, compounds, and mixtures. An **element** is a variety of matter that cannot be broken down into two or more different kinds of atoms. Iron, sulfur, oxygen, hydrogen, iodine, and calcium are typical examples of chemical elements. When any of these substances are broken down into the smallest divisible unit which retains the characteristics of the elements we find only one kind of atom. **Compounds,** on the other hand, are formed by a combination of two or more elements which are chemically united. Water, for instance, is a compound because it is formed from two elements—hydrogen and oxygen. By proper chemical techniques water can be broken down into these two component elements. The smallest divisible unit of a compound is known as a **molecule.** Water, therefore, is formed of molecules, and each molecule of water is composed of two atoms of hydrogen and one atom of oxygen. It is designated chemically as H_2O or HOH. All compounds are formed from molecules, but there are some cases where molecules do not form compounds. Oxygen, as it exists in an oxygen tank in the hospital, for instance, is an element, but it is composed of molecules. When oxygen exists in this pure state the atoms always unite in pairs to form molecules of oxygen composed of two atoms. Hence, we represent the oxygen as O_2. Since there is only one kind of atom

involved, however, we still refer to oxygen as an element. This is true of most of the gaseous elements, such as nitrogen (N_2) and chlorine (Cl_2) as well as oxygen. The majority of the liquid and solid elements, however, exist in the pure state without such a combination of their atoms into molecules.

There are about 100 different kinds of atoms that are known and hence an equal number of elements. However, through combinations of these atoms into various kinds of molecules, literally millions of different kinds of compounds can be formed. About 500,000 compounds have been identified and catalogued, but many more than this number exist or can be produced. Water is one of the simpler compounds. Common table sugar (sucrose) is somewhat more complex—each of its molecules is composed of 12 atoms of carbon, 22 atoms of hydrogen, and 11 atoms of oxygen ($C_{12}H_{22}O_{11}$). Some of the more complex compounds contain hundreds of atoms in each molecule.

Mixtures are combinations of different elements or compounds in which there is little if any chemical union of the combined parts. Furthermore, mixtures can be composed of different combinations of parts, but compounds always have the same proportions of elements in their make-up. For an example, we can mix water and alcohol and get a homogeneous fluid, but this is not a compound. We can make a water-alcohol mixture of many different proportions. This is not true of compounds—the same amount of carbon, hydrogen, and oxygen must always be present in sucrose. Since mixtures can be composed of different proportions of parts, it is evident that the chemical and physical properties of a mixture will vary with the variations in its component parts. A compound, on the other hand, having a fixed proportion of parts, will exhibit fixed chemical and physical properties.

The air around you is a familiar example of a mixture. The air which you are now inhaling is a mixture of nitrogen (an element), oxygen (an element), carbon dioxide (a compound), and vaporized water (a compound) which will vary in quantity depending upon the humidity of the air. There will also be very small amounts of other gases, perhaps some smoke, and a few other assorted things in this surrounding envelope which we call air. When you exhale air its proportions of oxygen, carbon dioxide, and water vapor will be different, but it will still be air.

The Nature of Atoms and Molecules

Since atoms are the basic building blocks of all states of matter we may well investigate their nature more fully. There was a time in

the rather recent past when it was thought that the atom was the smallest divisible unit of matter. Today we know all too well that the atom can be split with a tremendous release of energy. In spite of the great diversity of elements and compounds which are formed by atoms, all atoms have the same basic units in their composition. The variation comes from differences in the number of these units in the atom and the arrangement of these units.

The building materials of which atoms are constructed are mainly **protons, electrons,** and **neutrons.** Let us take a very simple atom, hydrogen, and show how these parts are combined to produce it in ac-
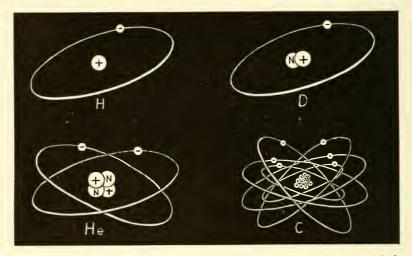
Fig. 3.2. Diagram of some simple atoms according to the generally accepted theory of atom structure. H, hydrogen, the simplest of the atoms with a single proton and a single electron. D, deuterium or heavy hydrogen, has an added neutron in its nucleus. He, helium, with two each of protons, neutrons, and electrons. C, carbon, a more complex atom with six each of protons, neutrons, and electrons. The carbon atom is drawn to a reduced scale.

cordance with the generally accepted theory of Bohr. In the center of this atom there is a nucleus consisting of one proton which carries a positive charge. Then, in an orbit moving around this nucleus there is an electron which carries a negative charge. There is another atom which also has one proton in its nucleus and one electron in its orbit, but it is heavier than hydrogen (about twice as heavy). We have recently learned that this is because the nucleus of this atom (deuterium or heavy hydrogen) contains a neutron which is neutral in its electrical charge, as well as the positive proton. Thus, neutrons add weight to atoms without affecting the charge. A carbon atom is somewhat more

complex—it has six neutrons and six protons in its nucleus and six electrons in a double orbit surrounding it. The atom has often been called a miniature solar system. There is always the central nucleus and the electrons revolving around it much like the planets revolve around the sun in our solar system. The number of electrons is always equal to the number of protons in the nucleus of an atom. Thus, a state of electrical neutrality exists within the atom.

Most of the volume of an atom is empty space as is true of our solar system, if we wish to carry the analogy a little further. The central nucleus makes up by far the greater portion of the mass of the atom. A proton has weight which is 1,800 times as great as an electron, and neutrons have essentially the same mass as protons. Thus, we have a relatively large central core of the atom around which revolve the infinitesimal electrons, with the greater portion of the atom being empty space. If we could enlarge an atom to a size 100 feet in diameter, then the nucleus would appear at the center about the size of a grape. The electrons would be tiny specks, too small to be seen with the naked eye, but they would be whirling around the nucleus at such terrific speeds that they would give a dim blur which would outline the outer limits of the atom.

Isotopes of Atoms

We hear a great deal about isotopes these days, especially the radioactive isotopes developed in connection with atomic research. Since such isotopes have great value in biological research, we shall learn something about them at this point in our study. An atom of some specific element behaves the way it does because of the number of protons and neutrons in its nucleus and the number and arrangement of electrons in its orbit or orbits. The number of neutrons may vary in some cases, but this will not change the chemical properties of the atom. It will change the weight of the atom, however. For instance, when an extra neutron is added to the single proton of hydrogen, we have heavy hydrogen (deuterium) which has twice the atomic weight of ordinary hydrogen. It has exactly the same chemical properties as ordinary hydrogen, although its speed of chemical reaction is slower because of its greater weight. Hence, rather than calling deuterium a separate element it is known as an isotope of hydrogen. A still heavier kind of hydrogen was discovered which has two neutrons in the nucleus. It was called tritium. When necessary, we distinguish between these three with superscripts, H^1, H^2, and H^3, and for most

isotopes we do not give them a separate name as is done for the isotopes of hydrogen.

Some isotopes of atoms are **radioactive;** that is, they give off high energy rays which can be detected by means of special instruments such as the Geiger counter. Such isotopes are sometimes called tagged atoms and are very valuable in biological research. The fate of certain minerals in an animal or plant can be detected by these tagged atoms. A small amount of a radioactive isotope of iodine can be given a guinea pig in its food and a day or two later the animal can be dissected and its organs analyzed with a Geiger counter. This instrument will show that most of the iodine has been taken up by the thyroid gland. Likewise it is possible to trace minerals from the soil and find out which plant tissues utilize them to the greatest degree.

Carbon fourteen (C^{14}) is a radioactive isotope of carbon (C^{12}) and is of great value in establishing the age of the remains of ancient forms of life. Since a certain proportion of the carbon in the carbon dioxide of the air is this radioactive form, all living things have this same proportion of it in their bodies. At death no more carbon fourteen is added and that which is present is gradually converted into ordinary carbon through the loss of electrons in the course of the continual radiation. It takes about 4,700 years for the amount of radioactive carbon to be reduced to one half, another equal period of time for it to be reduced one half again, and so on. Now, if an animal is uncovered and the remains are found to contain one eighth the amount of radioactive carbon that is found in living animals, we may conclude that it died approximately 37,600 years ago. There are some qualifications which must be considered in this method of reckoning time, but it is generally considered to be extremely accurate.

Ionization of Molecules

Whenever a teaspoon of sugar is put into water and stirred, we say that it goes into solution. The water looks the same as before, but it is somewhat thicker in consistency and it tastes sweet. What happened to the sugar? It has broken down into sugar molecules which become evenly dispersed throughout the water. If we dissolve table salt in water, however, the salt breaks down into particles below the molecule size which are called **ions.** A molecule of table salt is composed of two atoms, sodium (Na) and chlorine (Cl). Its chemical formula is NaCl. Now if this salt breaks down below the molecule size, you might think that it would break down into sodium and chlorine atoms. We know this is not true, however, for sodium is an ele-

ment which reacts violently when it contacts water, and chlorine is a greenish gas. Neither of these is formed when salt is dissolved in water. Instead, the molecules break down into sodium and chlorine ions. An ion differs from an atom in that it is unbalanced in its electrons and protons—it has either one extra positive or an extra negative charge. Table salt breaks down into a positively charged sodium ion (Na^+) and a negatively charged chlorine ion (Cl^-). Whenever water is evaporated from a salt solution these ions easily reassemble because of their opposite charges and the salt molecule is reformed. Thus, we can see that, when ionization occurred, one of the electrons from the sodium atom was transferred to the chlorine atom. This leaves the sodium with an extra positive charge, since the number of protons within the nucleus remains the same. The chlorine, on the other hand, becomes negative in its charge because of the addition of the electron to a system which was previously neutral.

Acids and Bases

Acids are substances which have a sour taste. We are all familiar with common acids found in the kitchen—vinegar which contains acetic acid, and sour milk which contains lactic acid. Other substances are known as alkalies or bases. These commonly have a bitter taste and feel greasy. Common baking soda dissolved in water forms an alkali solution. The stomach produces a common acid, hydrochloric acid, in very low concentration which aids in the digestion of food, but sometimes too much of this acid is produced with unpleasant symptoms. Many people take a little baking soda or other alkali in water to neutralize the excess acid.

Now, what is it that makes an acid an acid and a base a base, and why does one tend to neutralize the other? It is all dependent upon the ionization of molecules. Plain water undergoes a very slight amount of ionization—a few of its molecules will separate into hydrogen ions (H^+) and hydroxyl ions (OH^-). There will always be an equal number of each of these. Thus, we say that water is neutral—neither acid nor basic. When there is an excess of hydrogen ions in a solution, however, that solution will be acid. An excess of hydroxyl ions, on the other hand, renders it basic.

Suppose we dissolve some sodium hydroxide ($NaOH$) in water. It breaks down into ions (Na^+ and OH^-). This breaks the even balance of hydrogen and hydroxyl ions in the water, and the excess of hydroxyl ions makes the solution basic. Hydrogen chloride (HCl), on the other hand, breaks down into ions which results in an excess of hydrogen

ions and an acid is formed (hydrochloric acid). If we mix these two solutions together in the proper quantities, the excess hydrogen ions of the acid will unite with the excess hydroxyl ions of the base to form water and the solution will be neutral. It will contain free sodium and chlorine ions, and, if the water is evaporated, common table salt will result. Such a mixing is known as a chemical reaction and may be expressed as an equation:

$$HCl + NaOH \rightarrow NaCl + H_2O$$

We shall have occasion to study a number of chemical reactions in living matter which can be expressed in terms of equations.

Some acids are much weaker than others of the same concentration, because there is a lower degree of ionization. For instance, common vinegar contains about 3 per cent acetic acid, but it does not burn the mouth when used in foods. Neither does it react violently with aluminum cooking vessels when used in cooking. A 3 per cent solution of hydrochloric or sulfuric acid, on the other hand, would severely injure the mouth and literally eat up any aluminum containers into which it was placed. Now what is the difference? Hydrochloric acid, as we have already indicated, is almost completely ionized in water. On the other hand, the molecules of acetic acid are less than 1 per cent ionized. Thus, there are many more free hydrogen ions in a 3 per cent hydrochloric acid than in a 3 per cent acetic acid, and it is the free hydrogen ion that gives acid its reaction properties.

The degree of acidity or alkalinity is expressed in terms of **pH value.** Without going into details of the meaning of this, we can say that O represents maximum acidity and 14 represents maximum alkalinity. The figure 7 lies halfway between these two extremes and represents neutrality. Human blood has a pH value of about 7.3, which means that it is very slightly basic. Each point on the scale represents a tenfold change in ion concentration. For instance, a solution with a pH of 5 has ten times as many hydrogen ions as a solution with a pH of 6. Likewise, a solution with a pH of 9 has ten times as many hydroxyl ions as a solution with a pH of 8.

All living matter must exist within a rather narrow range on the pH scale. Human blood is normally about 7.3, but it can vary slightly above or below this point. If it ever falls as low as 7.0 or goes as high as 7.8, death results. Hence, we have a pH tolerance of less than 1 point on the scale in our blood. Plants grow best when the soil reaction is at a certain point on the pH scale and grow less vigorously when the pH goes above or below this point. If it gets too far above or below, the plant will not grow at all. Each plant is specific in its

tolerance—some do best in soil which is slightly acid, others do best when it is on the alkaline side. Farmers who want to get the most from their crops test the pH value of their soil and adjust it to the optimum needs of the specific crop to be planted.

Kinds of Mixtures

Chemists recognize nine different kinds of mixtures—gas in gas, gas in liquid, gas in solid, liquid in gas, liquid in liquid, liquid in solid, solid in gas, solid in liquid, and solid in solid. Since water is universally present in living matter and since water is a liquid, we shall learn more about the kinds of mixtures which substances can form with a liquid, using water as a specific example.

Solution. Whenever a substance is mixed with water, several different kinds of mixtures may result depending upon the size of the particles of the substance in the water. Some substances break down to form individual molecules, ions, or even atoms. Such a substance is said to be dissolved in the water, and the water being known as the solvent and the dissolved substance as the solute. This type of mixture is known as a solution, and the dissolved substance may be a solid, liquid, or a gas. Sugar is an example of a solid which dissolves in water to yield a clear solution. Alcohol is a liquid which dissolves in water, and oxygen is a gas which dissolves in water. (Were it not for dissolved oxygen, fish or other water animals could not live.) In every case, the physical and possibly the chemical properties of the water are altered by the dissolved substance. Its boiling and freezing point may be altered, as well as its ability to transmit electric currents, etc. Also, in the case of a solution, the dissolved particles do not settle out or rise to the surface on standing. When water containing solids in solution is evaporated, the solids will form in characteristic crystals in most cases. We call such substances crystalloids.

Suspension. If we place some powdered clay in water and shake it thoroughly, the water becomes cloudy and the particles will be suspended in it. The clay particles have not gone into solution, however, for each particle is composed of many molecules and these will settle to the bottom if this mixture is allowed to stand for a time. These particles can be seen under the microscope and appear as rather large bodies. This type of mixture is known as a suspension. Water in such a suspension has the same boiling and freezing points, as well as the other physical and chemical properties, that are found in pure water.

Emulsion. If we put a little olive oil in water and shake it vigorously, the oil will become broken into many tiny particles which be-

come evenly distributed in the water. The water will appear milky. Each of these tiny droplets of oil will consist of many molecules, because olive oil will not go into solution in water. Such a mixture of a liquid in a liquid is known as an emulsion. If we allow the mixture to stand for a time, the oil droplets will rise to the surface and soon the oil will be separated from the water.
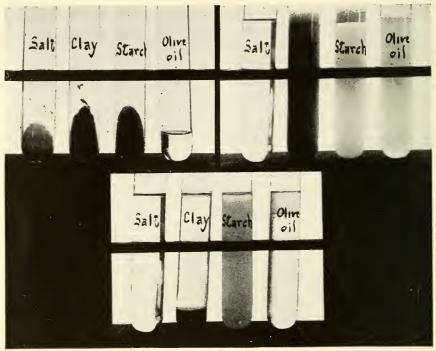
FIG. 3.3. The four types of dispersions which may occur in water according to the size of particles of the dispersed substance. The first photograph shows the substances before mixing with water, the second photograph shows them immediately after mixing, and the third photograph shows them several hours later. (Heat was applied to achieve the dispersion of the starch.) The salt forms a true solution, the clay forms a suspension and settles out, the starch forms a colloidal dispersion, and the olive oil forms an emulsion and rises to the top of the water.

It is possible to prevent the separation of the two parts of an emulsion by the addition of an emulsifier. An **emulsifier** is a substance in which the ends of the molecules are different—one is soluble in water and the other in oil. Thus, when an emulsifier is added to a mixture of oil and water it tends to bind the two together and prevent separation. Ordinary soap or any of the many types of detergents are examples of

emulsifiers. Soap (sodium stearate) will have the sodium end of its molecules soluble in water and the stearate end soluble in oil. Soap, therefore, can remove oil from your hands, whereas plain water cannot. The bile produced by the liver acts as an emulsifier of the fats which we eat. When there is a deficiency of bile, there cannot be a proper digestion of fats.

Colloidal Dispersions. A colloidal dispersion is composed of particles that are larger than the tiny units of matter in a solution, but smaller than the relatively large particles of matter in a suspension or an emulsion. The size of colloidal particles is usually given as lying between about .001 and .1 micron in their greatest dimension. (A micron is a thousandth of a millimeter.) This is the size that is just below the limits of the ordinary optical microscope, and thus colloidal dispersions appear homogeneous under such microscopes. Molecules as a whole, on the other hand, lie below the smaller limits of size of colloids. Colloids will not settle out or rise to the top upon standing —the particles are so small that they are kept evenly dispersed by the motion of the water molecules around them. In this respect they are like solutions, but, unlike solutions, colloids do not cause any great change in the chemical nature of the water in which they are dispersed.

The white of an egg is a good example of a colloidal dispersion. The albumin is present in the nature of finely divided particles dispersed in water. This type of colloidal dispersion is sometimes called a colloidal suspension, but should not be confused with the true suspension which we have previously discussed. Homogenized milk is another example of a colloidal dispersion. In fresh cow's milk the oil or fat is dispersed through the milk in rather large droplets and forms an ordinary emulsion, for the cream will rise to the top of the milk upon standing. When homogenized, however, the fat droplets are broken up into much smaller sizes which fall within the range of colloids. Thus, there will be no cream at the top of homogenized milk after it stands. Such a colloidal dispersion is sometimes called a colloidal emulsion, but again we should keep this distinct from the true emulsion previously described. Except for a few cases, solid colloidal particles do not form crystals when the water is evaporated.

Sols and Gels. Before leaving our discussion of colloids we should mention their unique ability to change from a liquid to a solid or semi-solid state and back again. If we mix gelatin with hot water, the particles of gelatin form a colloidal dispersion and a liquid results. This is called the sol state. The water forms a **continuous phase** and the particles of gelatin are in a **discontinuous phase.** As this mixture cools, however, the gelatin particles come together to form the con-

tinuous phase, the water is in between in the discontinuous phase, and the mixture is in the gel state. We can reheat the mixture and restore the sol state. The white of an egg is in a liquid state when it comes from the shell; but sufficient heat will cause the colloidal particles to fuse together, and the mixture goes into the gel state. We use gelatin, corn starch, egg white, and flour to form colloidal systems in the gel state to make many of our everyday foods more attractive and tasty.
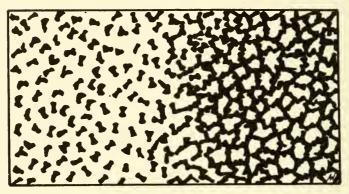
Fig. 3.4. From sol to gel. This diagram shows how the particles of a dispersion may change from a discontinuous phase to a continuous phase and thus change the nature of the mixture from a liquid to a jelly-like solid.

Changes in viscosity of protoplasm through slight changes in the sol-gel relationship account for many of the activities within a cell. When certain cells are viewed under the microscope, we can see an active movement of the protoplasm as it flows around in the cell. This is known as protoplasmic streaming and is brought about by such changes in viscosity of protoplasm in different parts of the cell. When an animal dies, the body is limp because of the relative fluidity of the protoplasm in the cells. Within a short time, however, the body becomes rigid; we say that rigor mortis has set in. The wastes which accumulate in the body of a dead animal bring about a change in the protoplasm from the sol to the gel state; we say that the protoplasm is coagulated. This causes the stiffening.

Organic and Inorganic Compounds

It was once said that organic compounds are those that can be produced only by living cells, whereas inorganic compounds do not need such a background of living matter. As the science of organic chemistry developed, however, it became possible to synthesize organic

compounds from inorganic substances. Today we even synthesize
such complex organic chemicals as hormones and vitamins. Hence,
we can no longer consider such a generalized statement as accurate. A
chemical analysis of organic compounds reveals the fact that carbon
is always an important part of such compounds. We have, therefore,
come to think of **organic compounds** as those containing carbon as a
part of their make-up. Contrariwise, we say that the **inorganic com-
pounds** are those which do not contain carbon, but we must modify
this latter statement slightly for there are a few inorganic compounds,

Simple sugar (glucose)

Ethyl alcohol

Acetic acid

Glycine (an amino acid)

FIG. 3.5. Structural formulas of some common organic compounds. Note the im-
portant, central position of carbon in each of these.

the carbonates, that do contain carbon. The carbon atom is so con-
structed that it can form a greater variety of compounds than is possible
for any other element. The variety of organic chemicals, therefore,
is very great. Several organic chemicals are shown in their structural
formulas in Fig. 3.5. A structural formula shows the relationship of
the various atoms which go to make up a molecule. Note that the
carbon atoms serve as a central point of attachment for many of the
other atoms in such molecules.

Chemical Composition of Protoplasm

Water. About 60 to 99 per cent of animal protoplasm is composed
of water. The exact amount of this substance varies with different
types of cells and different species of animals, but a typical average
is about 80 per cent. Water is an indispensable constituent of living

cells and a necessary part of the environment of cells. Water serves as the solvent for the dissolved materials in the cell and as a medium in which the larger particles are dispersed.

Inorganic Minerals. Within the protoplasm there will be a number of different inorganic salts dissolved and broken down into the ionic state. It is interesting to note that these salts are present in about the same proportions as in sea water. (The theory of a marine origin of life might explain this coincidence.) The most common of these is common table salt (sodium chloride), but there are also salts of calcium and potassium. We know that these salts must be maintained in a proper balance if the protoplasm is to function properly. A frog's heart, when removed and placed in water containing a little sodium chloride, will soon stop beating; but when the ions of sodium, calcium, and potassium are all three present in the proper proportions, it will beat for a considerable time. Slightly less than 1 per cent of protoplasm by volume consists of inorganic salts. The inorganic minerals also include certain dissolved gases, mainly oxygen and carbon dioxide.

Organic Compounds. Within the cell there are a number of different kinds of organic compounds. Three great classes of these organic compounds can be broken down with a release of energy. They are:

Carbohydrates. These are composed of carbon, hydrogen, and oxygen, with the hydrogen and oxygen present in the ratio of 2:1, which is the same as in water. The sugars, starches, and celluloses come under this heading. Simple sugar ($C_6H_{12}O_6$) is the product of food manufacture in a green plant, but usually these molecules are combined to form more complex sugars or starch for storage. Simple sugar is also found in animal cells, but may be converted into glycogen (animal starch) for storage. Cellulose is a very complex carbohydrate which forms the cell wall of many plants. It is not found within the protoplasm itself.

Fatty compounds. These are also composed of carbon, hydrogen, and oxygen, but the oxygen is present in much smaller quantity in proportion to the carbon and hydrogen. A typical animal fat from beef tallow (tristearin) has the formula: $C_{57}H_{110}O_6$. The true fats (lipins) can be broken down into two kinds of smaller molecules known as glycerol and fatty acids. There are other fatty compounds (lipoids) which contain these same two molecules, but contain other molecules as well. The outer plasma membrane of cells contains lipoids as well as the other cell membranes, such as the nuclear membrane.

Proteins. These compounds are an integral part of all protoplasm. They have the largest and most complex molecules of all compounds. Carbon, hydrogen, and oxygen again make up the bulk of the protein molecule, but there will also be atoms of nitrogen and usually some other elements such as sulfur, potassium, iron, etc. The chemical formula for hemoglobin (the substance which is found in the red blood cells) is: $C_{3032}H_{4816}O_{872}N_{780}S_8Fe_4$. (S is the symbol for sulfur and Fe for iron.) The important place of carbon in the protein molecule is shown by the formula. About one half the weight of the protein molecule is carbon. There are more hydrogen atoms, but hydrogen atoms are much lighter than carbon atoms. The proteins can be split into simpler compounds known as amino acids. About thirty different amino acids have been identified from the breakdown of proteins. Proteins cannot go into solution, but amino acids can. We shall learn the significance of this in the next chapter.

Proteins vary from organ to organ within an animal—those from cells of the kidney of a man will be somewhat different from those of the heart of a man. They may also vary in the same body part of different individuals of the same species—the blood of one person often cannot be mixed with the blood of another because of protein incompatibility. Finally, they vary from species to species—bone can sometimes be grafted from one person to another person, but bone from a dog cannot be grafted onto a human bone because of the protein differences in the bone cells.

REVIEW QUESTIONS

1. Chemical reactions take place more rapidly at high temperatures than at low temperatures. In view of what you have learned about the movements of molecules, why do you think this is true?

2. How may the movement of molecules be demonstrated even though the molecules themselves cannot be seen?

3. Tell how mixtures differ from compounds.

4. Why is the number of known atoms the same as the number of known elements?

5. Hydrogen has one proton and one electron, helium has two protons and two electrons, yet helium is four times as heavy as hydrogen. How can you explain this?

6. Oxygen has eight protons, eight neutrons, and eight electrons. An isotope of oxygen weighs one eighth more than ordinary oxygen. How many protons, neutrons, and electrons would this isotope have?

7. An ancient mummy is found with dating which indicates that it is 9,400 years old. What proportion of carbon fourteen would you expect to find in this mummy in comparison with the bodies of persons who have died recently?

8. How do ions differ from atoms?

9. If sulfuric acid is spilled on your hand, it will cause a severe burn, but acetic acid of similar concentration will not injure it. Both of these are acids; why do they react differently?

10. Suppose you put some grains of an unknown chemical in water and stir it up. How can you determine if this substance has gone into solution or not?

11. How does a suspension differ from a colloidal dispersion?

12. How are organic compounds distinguished from inorganic compounds?

13. Why can soap and water remove grease from your hands when water alone cannot?

14. How do the proteins differ from the carbohydrates and fats in their basic chemical composition?

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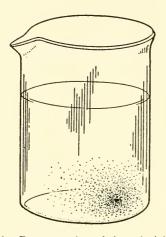
Movements of Materials Into and Out of the Cell

All cells are surrounded by a plasma membrane, and in most cases all of the materials which enter and leave a cell must pass through this membrane. There are a few cells, such as amoebae and white blood cells, which can engulf food in large masses, but the vast majority of cells have no such methods. The plasma membrane is composed of molecules of fats and proteins and is somewhat porous because of the openings between the molecules. Water, with its small H_2O molecules, is able to pass through this membrane readily. Also, certain substances which are dissolved in water exist as ions, atoms, and molecules which are small enough to pass through this membrane. Larger molecules and aggregations of molecules cannot penetrate this barrier. The cell, therefore, must obtain all its needed food and other materials in a form which is reduced to particles small enough to pass through the plasma membrane. Also, all of the waste products of the cell must be expelled through this membrane in the same state of solution. But from whence comes the force to cause these particles to move in the necessary directions? There is an important principle to explain it.

Diffusion

If we drop a crystal of some soluble dye in a beaker of water, the color will gradually spread out from the region of the crystal until the water is colored at the top of the beaker. If we leave it undisturbed for a long period of time the dye will become uniformly distributed throughout the water. Some force has caused this dispersion of the dye. What is it? It is the force of diffusion which can be explained as follows. As the dye is dropped into the water it begins to dissolve—the outer molecules of the crystal break off and float free in the water. We learned in Chapter 3 that molecules are always in motion, and in a liquid they are free to move about one another. This movement we remember comes from the energy of heat. In the immediate area of the crystal the number of molecules of the dye is greater than it is in

surrounding areas. Hence, there will be frequent collisions among the dye molecules in this area; but as they move out to the areas where they are less concentrated, such collisions are less frequent. The molecules of the dye will thus gradually spread out from the area around the crystal and eventually become evenly distributed. Once this has been accomplished the movements will be equal in all directions, and the solution will remain of equal density in all of its parts. To sum up, we say that diffusion is the movement of molecules from a region where they are more concentrated to a region where they are less concentrated.
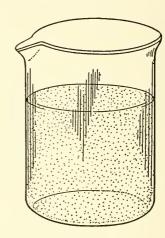
FIG. 4.1. Demonstration of the principle of diffusion. A crystal of dye dropped into a beaker of water begins to dissolve and the particles move away from the crystal toward the areas of lesser concentration. The second beaker shows the results of this reaction; the crystal has completely dissolved and the particles of dye are uniformly distributed throughout the water.

Let us consider an analogy which might help us to remember the principle of diffusion. Suppose we had a hundred blindfolded people tightly bunched in one corner of a large gymnasium and held in this corner by a surrounding rope. These people could move to a certain extent, but would be so crowded that they could not move about among one another very well. These we might compare to the crystal of dye with its molecules in the solid state. Now suppose that the rope was cut and the people were told to walk and keep walking. Those at the outer edge of the bunch could not move inward, but they could begin walking outward. As they moved out those farther in could be free to begin walking. There would be frequent collisions at first among the congestion of the newly loosed people, but each time they collided they would turn and move in a different direction. Those that moved out-

ward from the greater concentration of people would travel farther without collisions. When they hit the walls they would turn and go in a different direction. In the course of time there would be a gradual dispersion of people in the room until they would be about equally spaced in the room and would remain that way even though they continued walking and bumping. If we think of the particles of a dissolved substance in place of the people and the energy of heat as the force which keeps them moving, we have a rough impression of what happens in diffusion.

Diffusion will occur in gases as well as in liquids. If we open a bottle of strong perfume in one corner of a room, it will not be long before we can detect the odor in all parts of the room. The molecules of perfume diffuse from the area where they are more concentrated to areas of lesser concentration. It will even occur to a certain extent in solids, but since the molecules of a solid are not free to move about one another readily, such diffusion is extremely slow.

Before closing this discussion we should keep in mind the fact that the molecules of the solvent (water, etc.) are in motion as well as the molecules of the solute (dye, perfume, etc.). These moving molecules behave according to the same principles of diffusion as described for the solute and aid in the general mixing of particles in solutions of different density.

Diffusion Through a Membrane

A membrane does not stop the process of diffusion if the membrane is permeable to the particles of the dissolved substance. A sheet of rubber stretched between two solutions of different concentration would prevent diffusion because the rubber molecules which form the rubber sheet fit together so tightly that they will not permit any dissolved particles to pass through. There are many membranes, however, which contain openings between the molecules of which they are formed that are large enough to permit dissolved particles to pass through. Diffusion can take place through such permeable membranes. Minerals in solution in the soil diffuse through the outer membrane of the cells of the root hairs, and food in solution in your intestine diffuses into the cells lining the intestine because the membranes around these cells are permeable to dissolved particles.

Since the size of dispersed particles in a mixture varies greatly, it stands to reason that all such particles cannot pass through the openings between the molecules of membranes. A membrane which is permeable to the small dissolved particles of a true solution will not ordi-

narily be permeable to the larger particles of colloids, emulsions, and suspensions. Such membranes which will allow these smaller particles to pass through, but which hold back the larger particles, are called differentially permeable membranes. The plasma membrane which surrounds cells is such a differentially permeable membrane. To aid in your understanding of this, let us turn to another rather far-fetched analogy among the things with which you are familiar. Suppose we had a room divided down the center from floor to ceiling with a net of the general nature of a tennis net. On one side of the net suppose we had a general assortment of fruit—grapes, limes, grapefruit, and
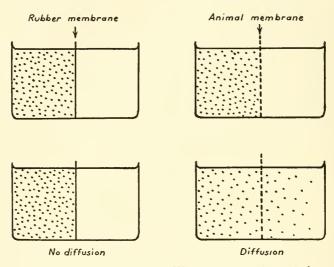
Fig. 4.2. Diffusion through a membrane. Whenever a membrane is impermeable to dissolved particles there is no diffusion. When the membrane is permeable, however, the particles pass through and there is diffusion through the membrane.

cantaloupes. We put several boys on each side of the net and tell them to start throwing this fruit at the net. When the grapes and limes are thrown, some of these will go through the openings in the net, but the grapefruit and cantaloupes will be stopped by the net and will remain on the same side. As the grapes and limes go through, the boys on the other side will begin throwing them back. Allow this to go on for some time, assuming that the fruit is not crushed in the process, and we will find that the limes and grapes are evenly distributed on the two sides of the net, but the grapefruit and cantaloupes remain on the side where they were at the beginning. Now think of the grapes and limes as small molecules of a dissolved substance and the grapefruit and cantaloupes as colloidal particles and perhaps you can have a better under-

standing of how a differentially permeable membrane allows passage of dissolved particles, but holds back larger particles. Many dissolved substances can pass in and out of the cell because of their small particle size, but the larger particles cannot.

Selective Nature of Living Membranes

In our discussion up to this point we have assumed that diffusion through a membrane was a purely physical process, with the passage of materials governed solely by the size of particles in comparison with the size of the openings in the membrane. This is generally true of nonliving membranes, but experiments show that living membranes exert some selectivity over the particles which diffuse through them. The plasma membrane is a sheet made of protein and fat molecules. The openings between these molecules permit water and certain small dissolved particles to pass through. We know that the molecules of dissolved glucose (a simple sugar) can pass through, yet some of the ions of salts which are smaller than the molecules of glucose do not pass through. The ions which do pass through will vary from time to time according to the need of the cell for these ions. How can such a selectivity be accomplished?

We learned in Chapter 3 that ions are either positively or negatively charged particles of matter. The living plasma membrane is also charged, but its charge may vary. When the charge is negative it will attract and admit positively charged ions, such as those of sodium and potassium, but will repel negatively charged ions, such as those of chlorine and carbonate. These negatively charged ions cannot even approach the membrane and thus have no opportunity to pass through. When the protoplasm has need of the negative ions to achieve a proper balance, however, the membrane is changed to a positive charge and conditions are just reversed.

It has also been found that molecules which are soluble in fat pass into the cell more readily than molecules of a similar size which are not soluble in fat. We have already mentioned the fact that the cell membrane contains molecules of fatty compounds. It is thought that the fat-soluble molecules first dissolve in the fatty portions of the membrane and then pass out on the other side of the membrane. If fat-soluble molecules are present in large quantities, they may dissolve out so much of the fat from the cell membrane as to cause a disruption of normal functioning. Alcohol and ether are fat-soluble compounds which act as anesthetics because they pass through the membranes of the cells of the nervous system so freely. When these substances reach

the cells in large quantities, they cause the cell membrane to disintegrate with resultant death of the cell.

Osmosis

Osmosis is a term used to describe a special type of diffusion of water through a differentially permeable membrane. An illustration will help to explain this process. Let us place a 5 per cent solution of
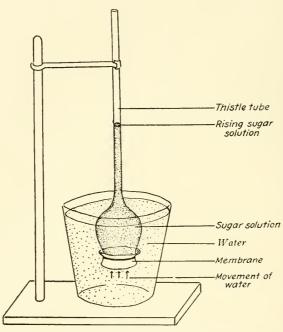
Fig. 4.3. Osmosis. This apparatus demonstrates the movement of water through a membrane by means of osmosis when there is a difference in concentration of dissolved substances on the two sides of a differentially permeable membrane.

sucrose (table sugar) in water into a membrane which is permeable to water, but not readily permeable to the sucrose molecules. Such a membrane can be prepared by spreading a thin film of collodion in a beaker and allowing it to dry, or we may use some natural membrane such as the bladder from a pig or the skin from the leg of a frog. The membrane containing the sugar solution is then suspended in a jar of plain water as shown in Fig. 4.3. Within a few minutes it can be seen that the volume of the solution within the membrane is increasing, for the mixture will begin to rise in the open tube. Water

is coming through the membrane and causes this increase in volume. Such movement of water through a membrane toward an area of greater concentration of a dissolved substance is known as osmosis. Now let us try to determine the cause of this unequal movement of water molecules through the membrane.

We must remember that water molecules are moving just the same as the molecules of a dissolved substance. We have a membrane separating solutions of different concentrations, but there can be little diffusion of the sucrose molecules through the membrane because they are too large. Water molecules, on the other hand, can pass through freely because of their smaller size. On one side of the membrane we have 100 per cent water (water with no dissolved substances in it), but on the other side of the membrane we have only 95 per cent water, for 5 per cent of the solution is sugar. Hence, according to the principles of diffusion which we have already learned, the water molecules will diffuse through the membrane from the area where they are more concentrated to the area where they are less concentrated. Of course, molecules of water can pass through in both directions, but more water molecules will go through the membrane from one side for the simple reason that there are more water molecules on that side to bombard the membrane. This will cause an increase of volume in the sugar solution, and a force will be generated that will cause a rise in the tube against the force of gravity. With this new concept we can say that osmosis is the diffusion of water through a differentially permeable membrane from an area of greater concentration of water to an area of lesser concentration of water. (It is possible to have osmosis of other liquids, but since water is the primary solvent in living material we use water in our definition.)

The water will continue to rise in the tube until the pressure of gravity overcomes the osmotic pressure. When the force of gravity becomes great enough it will force the water molecules back through the membrane as fast as they diffuse through by osmosis, and an equilibrium will be established.

Diffusion and Osmosis in the Cell

The protoplasm of a cell consists of a series of dispersion systems as we learned in Chapter 3. The inorganic minerals and the sugars exist in true solution, but the more complex carbohydrates, proteins, and some of the fatty compounds exist as colloidal particles. Also, there will be some of the fats in the emulsion state and aggregations of particles of various kinds in suspension. Since the plasma mem-

brane will allow only certain dissolved particles to pass in, we might ask the question, "How did these other materials get into the cell?" To illustrate, let us consider some of the cells in your finger. To trace the source of its protoplasm we must go back to the food which you eat.   Food, when it is eaten, is seldom in a state that can diffuse through cell membranes.   A few simple sugars require no change, but the major part of our food must be digested before we can benefit from it.
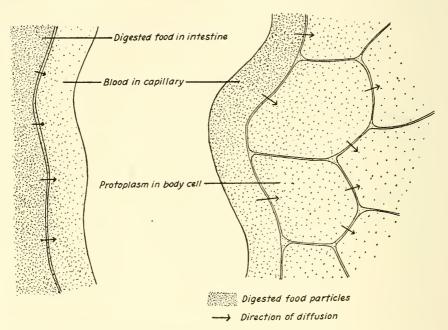
Fig. 4.4.   Diagram illustrating diffusion of digested food. Note that the concentration of food in the intestine is greater than in the blood, so diffusion takes place through the membranes into the blood within the capillaries. When this blood reaches the body cells it contains more food than the protoplasm of the cells and thus the food diffuses into the cells. As cells in contact with the capillaries receive the food, it may then diffuse into surrounding cells through the same principle.

And what is digestion?   It is simply the breaking down of large molecules and the even larger particles of colloids and emulsions into simple molecules which can diffuse through cell membranes.   Colloidal protein particles, for instance, are broken down into the soluble amino acid molecules which can pass through these membranes.

After digestion, the dissolved particles within your intestine are more numerous than they are in the blood which comes in close contact with the digested food.   Hence, diffusion causes the digested food

to pass into the blood which carries it all over the body. When this blood, rich in dissolved food, reaches the cells of your finger there is again an unequal distribution of molecules of digested food—within the cells of your finger there is less food than in the blood. Hence, diffusion again causes the movement from an area of greater concentration to an area of lesser concentration which is within the cell. Within the cell, diffusion continues and distributes the food to all parts of the protoplasm. In case there are adjoining cells which are not in contact with the blood, the food will continue to diffuse from cell to cell until the concentration is equalized in all.

Once within the cell the various amino acids may again be reconstructed into proteins which form an integral part of your protoplasm. The simple sugar may be changed into the more complex glycogen for storage. Fatty compounds may be formed from the fatty acids and glycerol which diffuses through the membrane. Thus, the protoplasm is constructed—first food materials are broken down to a size small enough to diffuse through the cell membranes, and then these small particles may be reconstructed into more complex compounds within the cell. It is through enzymes that these various changes are accomplished. We produce enzymes in our digestive organs which break the food down, and there are enzymes within the cells of our bodies that cause reconstruction of these products of digestion.

When waste products are generated within a cell, they must be in a soluble form which can pass out through the cell membrane. Carbon dioxide, which is produced when food is used within the cell with an energy release, accumulates so that there is more of this compound within the cell than there is in the surrounding blood. Hence, it will diffuse into the blood, but when this blood reaches the lungs it is richer in carbon dioxide than the air in the lungs and we have a diffusion from a liquid into a gas. When proteins are used for energy there will be certain nitrogen-containing wastes that also accumulate in the cell. By diffusion these pass out into the blood and are removed from the blood by the kidneys.

Now what about the movement of water into and out of cells through osmosis? If we place some red blood cells in plain water, they will begin swelling and in a short time will burst from the internal pressure. The protoplasm of the cells contains substances in solution, but plain water has none. Hence, through osmosis water begins moving into the cell and the cell begins to swell until the outer membrane gets so tight that it bursts. If we place red blood cells in water with 0.87 per cent salt dissolved in it, they will remain normal—the passage of water into and out of the cell will be equal because the dissolved minerals within

the cell are the same in concentration as the salt in the water outside. Finally, if we place some red blood cells in a 5 per cent salt solution, the water will pass out more rapidly and the cells will shrivel and shrink. We can restore the cells to a normal state by placing them in the 0.87 per cent salt solution.

Thus we see how cells respond to variations in the concentrations of solutions around them. All cells of the body are not so fragile as red blood cells, and most of them do not burst when placed in plain water, but they will swell. Everyone has noticed how the skin of the hands will become soft and swollen when the hands are kept in water for a long period of time. This can be prevented if some salt is placed in the water to prevent the cells of the skin from absorbing water through osmosis. Physicians often advise patients to soak a sprained ankle in hot water containing some Epsom salts. This prevents the undesirable

Isotonic   Hypotonic   Hypertonic
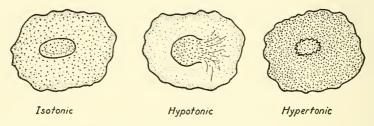
FIG. 4.5. Reaction of red blood cells to solutions of different concentration. The cell remains normal in the isotonic solution, it swells and bursts in the hypotonic solution, and it shrinks in the hypertonic solution.

swelling of the cells of the skin and will help in reducing a swollen area by removal of water through osmosis. This effect of Epsom salts is especially noticeable when it is taken internally as a cathartic. The ions of Epsom salts are not readily diffused through the cells of the intestine, and they raise the concentration within the intestine to a point where water is withdrawn from the body by osmosis; this keeps the contents of the intestine in a highly liquid state.

A solution which has the same concentration of dissolved substances as is found in the protoplasm of certain living cells is said to be isotonic to those cells. Most drugs which are prepared for injection into the human body contain 0.87 per cent sodium chloride to make them isotonic with the cells of the body. Plain water injected into the blood stream would cause the bursting of many red blood cells before it mixed with the blood plasma. Also, nose drops are prepared in an isotonic solution to prevent irritation to the delicate cells lining the nasal cav-

ity. All of you have experienced the unpleasant reaction that comes when water is drawn up the nose. This is due to the swelling of the cells in the nasal cavity. If you put a little salt in water, however, it can be drawn up the nose without such irritation. In fact, this is sometimes done to help clear the phlegm from the nasal cavity during a bad cold. When you go swimming in the ocean and get water in your nose, there will be some irritation because in this case there is too much salt in the water. Sea water is about 3.5 per cent salt and, therefore, causes some cell shrinkage when it contacts delicate tissues of the body. Plain water is said to be hypotonic to the cells of your nasal cavity, whereas sea water is hypertonic.

Filtration

Before leaving our discussion of the movement of materials into, out of, and within the cell, we should bring out a method of movement under pressure known as filtration. Whenever pressure becomes great enough, it can force water and dissolved particles through a membrane against the force of osmosis. We have already learned how the force of gravity can do this in a nonliving membrane. The blood is pumped to all parts of the human body by the pressure generated by the heart beat. When this blood reaches the tiny capillaries which have walls only one cell in thickness, some of the water and dissolved substances will be squeezed out by mechanical pressure. This fluid bathes the cells and is a great aid in carrying dissolved food to cells which are not in contact with blood vessels. It will re-enter the blood stream through the lymph vessels so that there is not a continual loss of such large quantities of fluid from the blood. Also, at the kidneys filtration comes into play to aid in the removal of wastes from the blood. Blood within the capillaries is under rather high pressure, and there is a mechanical squeezing of water and dissolved minerals into small tubules within the kidneys.

Filtration saves many cells from bursting when they are placed in hypotonic solutions. When the pressure within the cell increases to a certain point, filtration forces water out as fast as it comes in and an equilibrium is reached. If the cell membrane can withstand this critical pressure the cell is saved.

From the discussion in this chapter we can readily see that the movement of materials into and out of cells is a very important part of the activities of all forms of life.

Surface-Volume Ratio of Cells

In Chapter 2 it was pointed out that cell duplication was necessary to keep cells from growing so large that they could not have sufficient exchange of materials through their plasma membranes to support life. The efficiency of cells is dependent upon their small size. A small object will have a greater surface area in proportion to its volume than a larger object of the same shape. Since the rate of diffusion is dependent upon the exposed surface, it becomes evident why the small size is important.

To explain this principle more fully let us think of a cube measuring four inches in each direction. This cube would have ninety-six square

4 inches

2 inches

1 inch

1.5 : 1

3 : 1

6 : 1

Surface - volume ratio
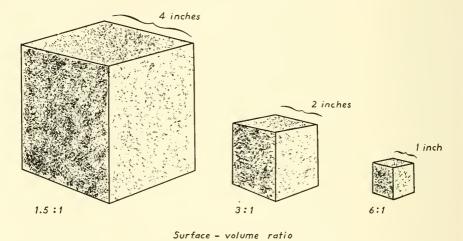
FIG. 4.6. Effect of size on the surface-volume ratio. As the size of a cube becomes smaller, it has a relatively greater exposed surface.

inches on its surface and sixty-four cubic inches of volume with a surface-volume ratio of 1.5 to 1. If we now take a cube which measures only two inches in each direction, we find that it has twenty-four square inches of surface, but is only eight cubic inches in volume. The surface-volume ratio here is 3 to 1. A one-inch cube would have six square inches of surface and one cubic inch of volume, a ratio of 6 to 1. Thus, we see how the surface-volume ratio increases as objects get smaller.

We see this principle illustrated over and over again in the physiology of living things. Human red blood cells are very small and are, therefore, much more efficient than they would be if they were larger.

If their diameter were doubled, the same volume of blood cells could carry only one half as much oxygen as they now can. If their diameter were quadrupled, they could not carry enough oxygen to keep us alive, even though in this enlarged condition they would still have a diameter of only about one thousandth of an inch.

When a portion of a human lung is viewed under the microscope, it can be seen that the tissue is composed of many very tiny air sacs. This gives great exposed surface which allows ready diffusion of oxygen and carbon dioxide. If the lungs were hollow like a balloon there would be so little surface exposed to the air that it would be impossible to obtain sufficient oxygen to support life.

The surface-volume ratio of the entire body is also very important in determining many of the physiological processes and life habits of animals, as we shall see as we proceed with our study.

REVIEW QUESTIONS

1. Why is the plasma membrane of such importance in the physiology of the cell?

2. Explain how diffusion through a dead membrane in the laboratory differs from diffusion through the living plasma membrane.

3. If a lump of sugar is dropped in a glass of water, the water will eventually taste sweet at the top of the glass even though the water is not stirred. Explain why this is so.

4. Diffusion proceeds more rapidly in a cup of hot coffee than in a glass of iced tea. Explain.

5. Why is it that the cells cannot utilize most foods if they are injected into the blood stream rather than taken into the body by the mouth?

6. A little fertilizer on a lawn will make it grow better, but a large amount may kill the grass. Explain.

7. How does filtration differ from diffusion?

8. If you slice potatoes and place them in plain water they become crisp, but when placed in rather strong salt water they become very limp. Explain.

9. When medicines are injected into the body they are usually dissolved in a 1 per cent salt solution. Why?

10. From your knowledge of diffusion, work out a logical explanation of why carbon dioxide is absorbed by the blood from the body cells and given off from the blood into the air spaces of the lungs.

11. A bacterial cell may double its size in as short a time as twenty minutes. Such rapid growth is unthinkable in the larger animals. Explain fully.

5

Vital Animal Life Processes

All animals must carry on certain vital life processes if they are to continue to live and reproduce their kind. The animal may be a tiny one-celled organism, such as an amoeba; a larger mass of protoplasm, such as a jellyfish; or a highly complicated aggregation of cells, such as a human being—all must share these basic reactions. First we shall consider the life process known as digestion which is necessary for normal animal nutrition.

Digestion

Food, as it is taken into the animal body, is seldom in a form that can be used by the cells. For instance, if instead of eating your breakfast this morning you had ground it finely and injected it into your veins, you not only would have gotten no nourishment, but it would have killed you. The same food obtained through the normal channel of your mouth is now circulating through your veins and nourishing the cells of your body. Somewhere between the eating and the absorption into the blood, chemical changes took place in that food which made it usable by your body. Enzymes are the agents which accomplish this transformation. We shall find that in some of the simpler forms of animal life the raw food particles are taken into the cells and digestion is accomplished by enzymes within these cells. This is known as **intracellular digestion.** In more complex animals there are special organs for the production of these enzymes, and they are released into other organs such as a stomach or intestine where digestion takes place. The digested food is then absorbed and distributed to the cells of the animal's body. This is **extracellular digestion.**

We use the term **ingestion** to refer to the intake of food into the body. Most animals have a mouth for ingestion, but we shall find some simple animals which can engulf food at any part of the body. After digestion there is a residue of matter which could not be broken down into soluble form by the enzymes. Since this residue is of no value to the animal, it must be expelled from the body—this is **egestion,**

Hence, the typical digestive process begins with ingestion and is followed by digestion, absorption, and egestion.

Respiration

Food in itself is of no value to an animal for energy until it can be combined with oxygen. Carbon dioxide is always produced as a result of this oxidation and must be eliminated from the animal body. It is through the very vital process of respiration that oxygen is obtained and carbon dioxide given off. Lungs and gills are specialized organs used by higher animals for this purpose. In some animals the skin is a major organ of respiration. Frogs, for instance, have lungs, but they depend upon diffusion through their skin for a large part of their oxygen supply. If the skin of a frog is allowed to dry, thus making it impermeable to oxygen, the frog will die even though the lungs are functioning to their fullest capacity. In the earthworm there are no specialized organs of respiration—the oxygen absorption and carbon dioxide release must all take place through the moist skin. In the one-celled animals and a few of the simpler multicellular animals, diffusion of oxygen into the cell and carbon dioxide out of the cell take place directly from the medium in which the organism lives.

Water animals obtain their oxygen from the air which is dissolved in the water. Fish will die if they are kept in crowded conditions, for they will use the oxygen in the water faster than additional oxygen can dissolve from the atmosphere. Also, any aquatic animal will die if it is placed in water that has been boiled and cooled without allowing time for air to dissolve, because boiling drives air from the water. Some people who raise tropical fish keep air bubbling through the water in their aquariums constantly to insure a plentiful supply of oxygen for the fish and to aid in the removal of carbon dioxide.

The process of taking oxygen into the body and of giving off carbon dioxide is spoken of as external respiration. The actual utilization of the oxygen within the cell with the production of carbon dioxide as a by-product is known as **cellular respiration**. We can represent this type of respiration with the oxidation of glucose:

$$\underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2} \xrightarrow{\text{enzymes}} \underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O} + \text{energy}$$

This is the basic formula for most energy release within the cell. The complex sugars, starches, and even proteins are broken down into the simple sugar, glucose, before oxidation. Fats may be oxidized without this conversion into glucose, but since fats are low in oxygen, a larger quantity of oxygen is used, with the result that more heat is produced.

Excretion

In the complicated process of cell metabolism there are other wastes besides carbon dioxide. These wastes must be removed from the cell and from the animal body with regularity or the animal will die. Excretion is the name given to the process of the removal of these wastes.
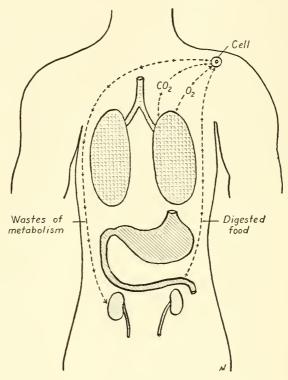
Fig. 5.1. Relationship of four vital life processes to metabolism in man. This diagram shows how a cell in the shoulder region is dependent upon digestion, respiration, excretion, and transportation. If any one of these fails to perform its functions properly, metabolism stops and the cell dies. (The dash lines do not show the exact course of transportation—they merely show the source and destination of the products.)

If animals could live on a diet of pure carbohydrates and fats, there would be no need for excretion, since these compounds contain no elements besides carbon, hydrogen, and oxygen; and when they are oxidized they produce only carbon dioxide and water as by-products. The food of all animals, however, contains other elements; it must contain other elements, because protoplasm cannot be constructed of only carbon, hydrogen, and oxygen. Nitrogen is one of the primary

elements required for the construction of protoplasm. The necessary nitrogen is obtained from protein foods. Not all the protein eaten is used for the building of protoplasm—practically all animals eat more protein than the bare minimum required for the construction of new protoplasm. Excess protein is used for energy. Enzymes within the cell break down the protein into its component amino acids. Then other enzymes split the amino acids into glucose and the amino radical, NH_2. The glucose is oxidized with energy release and the NH_2 is converted into nitrogenous wastes such as urea, $CO(NH_2)_2$. Urea composes one of the primary wastes which is excreted from the human body in the urine. The amount of urea in urine is an indication of the amount of protein in the diet. When a person eats heavily of the protein foods, his urine will be rich in urea, and *vice versa* when the diet is low in proteins.

The proteins which are broken down for energy, however, do not seem to be the ones which were recently eaten. By using a recent development of atomic research known as tagged atoms, it is possible to trace the source of the nitrogen which is in the diet. These radioactive isotopes of nitrogen can be traced, and the source of the nitrogen used in the body can be determined. When food containing this radioactive nitrogen is eaten, it goes to form a part of the protoplasm of the cells, whereas some of the existing protein of the protoplasm is broken down for energy release. The urea of the urine will contain little radioactive nitrogen, since most of it stays in the cells. This shows that animal bodies are constantly constructing new protoplasm from their food and breaking down existing protoplasm for energy. This process might be compared to a man living in a house furnished with wooden furniture. When new wood is brought in, he uses this wood to construct new furniture and tears down his old furniture for fuel in the fireplace. Thus, no matter how long the house stands, it will always have new furniture. Likewise, there seems to be a constant turnover of the elements which form the vital protoplasm of animal bodies.

Excretion, like respiration, is a comparatively simple process in the small water animals where the wastes of metabolism can diffuse out of the body into the surrounding water. In the larger animals, however, there must be special organs to remove this waste and excrete it. Kidneys take care of this function in man and other higher animals. The importance of the excretory process is demonstrated when a person's kidneys do not function properly. The excretory wastes accumulate in his system and we say that uremic poisoning has developed. He will die in a short time if the proper function of the kidney is not maintained.

Sensory Reactions

The processes of digestion, respiration, and excretion usually take place more or less automatically within an animal's body. In addition, there are many reactions which come about as a direct adjustment to external stimulations. These are vital reactions which every animal must make if it is to survive the constantly changing conditions of environment. In the complex animals there is an elaborate series of sense organs and nerves which detect external stimulations, and muscles all over the body which respond to nerve impulses and make the proper responses. Not a day passes that we do not react to some dangerous environmental situation to save ourselves from serious injury or death. A hand that accidentally touches a hot stove is quickly removed as the sense organs in the skin are stimulated by the heat, and the muscles of the arm quickly respond to draw the hand away. We jump to safety at the sight of a rapidly approaching automobile. The sight and odor of good food stimulate our desire to eat, and our muscles carry the food to our mouths. We could multiply such examples of stimulus and response which under usual circumstances lead to our survival. A human being could not survive long without some senses to detect changes in the outside environment and muscles to respond to these changes. Of course, many people live with one or two of their senses lacking, sight and hearing most commonly, but some senses must remain. Also paralysis may incapacitate some muscles, but certain vital muscles must retain their power to function. When vital nerve centers are destroyed by disease or injury, death results.

In the animals which are not so highly developed, there is a correspondingly lesser degree of development of the sensory reactions, but they are present even in the one-celled animals. Studies of one-celled animals show that they can detect the presence of food and make an effort to obtain it; they can avoid substances that are unfavorable to them; they can respond to changes in temperature and light intensity. It is remarkable how many activities can be performed by one cell when it is the only cell of an animal body. As we survey the animal kingdom, it will be interesting to note how the various senses are developed, along with the ability to respond to the stimulation of these senses.

Transportation

All animals are faced with the problem of moving materials from one part of the body to another. Among the smaller animals living

in water, the problem can be solved by simple diffusion of dissolved products from one part of the body to another, but as the animals become larger such a method cannot suffice. Blood and lymph are the agents which serve to carry substances from one part of the body to another in the higher animals. These body fluids, however, are of no value as media of transportation unless they are moving. In the higher animals pumping mechanisms called hearts keep the fluids in constant motion. In animals intermediate between the one-celled animals and these higher forms, there is a variety of mechanisms of transportation. In jellyfish and flatworms the digestive system branches to all parts of the body and serves as a means of distribution. The starfish which lives in the ocean actually takes sea water into its body and circulates it to all five arms. Insects have blood vessels which carry the blood from the heart to all parts of the body, but no vessels to bring it back—it collects in cavities and finally accumulates in a space around the heart. But whatever the method used, transportation of materials throughout the body is a necessary life process.

Reproduction

Although this life process is not absolutely essential for the existence of an individual, it is certainly necessary for the continued existence of the species. Even in a complex animal like a human being, it is possible to remove the reproductive organs and have life continue. All animals, however, are faced with the certainty of the termination of their lives as individuals. Every species, therefore, must have some way of producing new animals like themselves, if the race is to continue to exist.

The simplest method of reproduction is known as **fission**. By this process an animal divides itself into two parts and each part continues to grow as a separate individual. This method is found in the one-celled animals and some of the simple worms. An animal with this method of reproduction does not grow old and die—it grows and divides. Nevertheless, its life as an individual is terminated when it splits in two and begins existence as two separate organisms.

Closely related to this is the method of reproduction known as **budding**. Small buds appear as outgrowths from the body of an animal, and these grow until they form a mature individual. Sometimes the buds break off to form separate animals and sometimes they remain attached so that a cluster of animals remains together to form a colony. Some of the jellyfish are formed by the first method and some of the sponges by the second. Since there is no union of animals or cells in

either fission or budding, these methods are known as **asexual reproduction**—reproduction without sex.

In most forms of animal life **sexual reproduction** is the only method. Sexual reproduction involves a method of mingling the genes from different cells and in most cases from different animals. Nearly all animals with sexual reproduction produce eggs and sperms, each of which carries approximately the same number of hereditary characteristics, the genes. When the sperm fertilizes the egg, there is a mingling of genes from two different individuals and this produces a variety in the offspring which could not be possible with asexual reproduction. In some of the one-celled organisms, two animals will come together and trade genes in a form of sexual reproduction known as **conjugation.** This achieves the variety that comes with the mingling of genes even though no sperms or eggs are produced. There are many of the simpler animals which have both sexual and asexual reproduction. Only in a few of the one-celled animals does asexual reproduction take place exclusively. The biological importance of this random assortment of the genes in sexual reproduction will be brought out as we continue our study.

Tissues, Organs, and Organ Systems

In the small animals with a simple body organization, the cells are somewhat alike all over the body; but as animals become larger there is a gradual increase in specialization—some cells are formed which perform certain specific functions most efficiently whereas other cells are specialized in different ways for different functions. In such animals the cells are organized into tissues. A **tissue** is defined as a group of similar cells performing a particular function. Tissues may secrete intercellular materials as in the case of bone tissue, which consists of bone cells surrounded by a hard matrix containing lime salts. Blood is a tissue which consists of cells together with a fluid matrix in which the cells, called corpuscles, float. Your outer layer of skin, the epidermis, consists of epithelial cells with a very thin layer of sticky secretion which holds them together, yet allows them to rearrange themselves. We shall study tissues in more detail when we study the structure of the vertebrate animal.

Different kinds of tissues combine to form **organs,** such as the stomach, kidney, and thyroid gland. The stomach, for example, consists of four distinct layers, each composed of different kinds of tissues; and the combined action of these tissues is necessary if the stomach is to perform its specific functions in the role of digestion.

Groups of organs are combined to form **organ systems**—the stomach, small intestine, large intestine, liver, and pancreas are organs which aid in digestion and therefore we say they belong to the digestive system.

Organ Systems

The simpler animals carry on their vital life processes without any specialized organ systems; but as animals become larger and more complex in their morphology, the various organ systems are developed
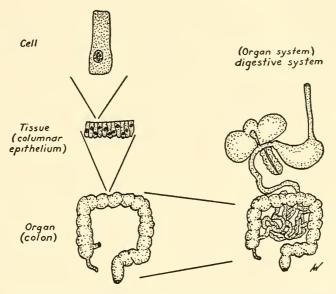
Fig. 5.2. Diagram to show how cells make tissues, tissues make organs, and organs make organ systems. This is the digestive system of man.

and perform the necessary life functions. We will list the organ systems which are found in the highest forms of animals, the vertebrates. In less complex animals, some of the systems may be present and others lacking.

Digestive System. This system takes care of ingestion, digestion, absorption, and egestion.

Respiratory System. This system functions to absorb oxygen from the environment (air or water) and gives off carbon dioxide.

Excretory System. This system removes and excretes the wastes of metabolism.

Reproductive System. This system includes special organs which have the specific function of propagation of the species.

Nervous System. This system coordinates the various parts of the body. In the simpler animals it may consist of only a network of nerves, but as animals become more complex the nervous system becomes much more extensive. There may be a variety of sense organs which pick up stimulations of different kinds, a nerve center known as a brain, a nerve cord, and nerves running to all parts of the body.

Muscular System. In the simplest of animals all of the cells have the power of contraction and all share in producing body movements. As cells become specialized, however, they tend to lose this power and special cells are set aside to take care of movements of the body.

Circulatory System. This system becomes necessary as animals become so large that materials cannot be distributed over the body by simple diffusion. A circulatory system consists of a fluid, usually designated as blood, which is kept moving in a circuit around the body by some pumping force, such as a heart.

Skeletal System. This system supports the soft parts of the body and protects them from injury. Muscles are attached to the skeleton as an anchorage. The skeletal system may be divided into two major types. The exoskeleton is found on the outside of the body and is best illustrated by the hard outer covering of the insects. The endoskeleton is found inside the body and is illustrated by the human skeleton.

Integumentary System. This system includes the skin and its numerous appendages, such as hair, nails, spurs, horns, hoofs, and glands. The primary function of this system is the protection against infection, water and heat loss, and abrasion. Many aquatic animals also use their skin for respiration.

Endocrine System. This system is comprised of a series of glands in various parts of the body and they secrete products called hormones which regulate many important body activities. For instance, there is a thyroid gland located in the neck of man which secretes a hormone that regulates the rate of metabolism in cells all over the body. Hormones are spread over the body by means of the blood circulation.

As we survey the animal kingdom it will be interesting to note the development of these various organ systems.

REVIEW QUESTIONS

1. Name the four vital life processes necessary for all animals and tell why each is necessary.

2. Distinguish between intracellular digestion and extracellular digestion.

3. List the variety of methods used for respiration in animals.

4. How does cellular respiration differ from external respiration?

5. Give the chemical equation for the oxidation of glucose within the cell.

6. Sometimes persons with kidney trouble are put on a low protein diet. What would be the reason for this?

7. Tell how radioactive isotopes may be used to study the relation between cell metabolism and excretion.

8. Some of the small, simple animals have no excretory organs, yet larger animals cannot exist without these organs. Explain.

9. Distinguish between sexual and asexual reproduction.

10. Explain the relationship between cells, tissues, organs, and organ systems.

11. List the organ systems which are present in the higher forms of animal life.

6

Animal Classification—Taxonomy

In the files of the Federal Bureau of Investigation (F.B.I.) in Washington there are millions of fingerprints of various types of law violators in the United States. To one unfamiliar with the methods of crime detection it might seem impossible to identify a criminal by comparison of these records with fingerprints found at the scene of a crime. It would appear to be a hopeless task to match a fingerprint with one of the millions on file. Yet, experienced F.B.I. agents can accomplish this and identify the criminal within a matter of minutes. How is this possible? Through a systematic method of classification.

There are over a million species of animals which have been identified and named up to date. Hundreds of new species are being discovered and added to this list each year. Without a systematic means of classification, these would form such a conglomeration that it would be impossible to locate the name and description of any particular animal. It would be similar to searching for a book in a large library in which the books were not classified, but stacked indiscriminately on the shelves. It is thus apparent that there must be an efficient method of classification. Taxonomy is the word used to describe the phase of biology dealing with classification.

Taxonomy was in a confused state before 1735. Aristotle and others had worked out a crude system of classification, but there was no authority to which one could turn to settle disputes on the names of plants and animals. At that time, however, a great Swedish naturalist, **Carolus Linnaeus,** realizing the need for a systematic approach to classification, published his great work *Systema Naturae.* In this book he attempted to name and briefly describe all the existing plants and animals known to him. The book went through twelve editions, each of which contained additional species until, in the final edition, 4,378 species were included. Although this is a far cry from the great number known today, Linnaeus laid the foundation for the modern method of classification.

The tenth edition of the book is considered the actual beginning of modern classification. It was published in 1758. In this edition each species name was limited to one term. The *International Code of Zoologi-*

cal Nomenclature has ruled that no name given prior to 1758 shall be recognized—this eliminates the confusion caused by the fact that different methods and different names were used in the different countries before this date. In case two different names have been given to the same animal, this code provides a law of priority. This law states that the first name proposed for an animal during or after 1758 shall be considered the official name, provided the proper conditions of publication have been observed. A universal, efficient means of naming and arranging living things was the great contribution of Linnaeus.

Plant Life, Swingle, D. Van Nostrand Co., Inc.

FIG. 6.1. Linnaeus, the great Swedish naturalist who originated our modern method of classification of living things.

It is impossible to study any branch of zoology without including some taxonomy, for taxonomy is the biological way of naming things and, just as it is difficult to talk about people without calling their names, it is difficult to talk about any phase of zoology without using the names of the animals under consideration. Many beginning students shudder when they look at the bewildering array of four and five syllable words with Latin endings that greet them within the pages of a zoology textbook. Studied intelligently, however, these words may be easier to learn than short three or four letter words, because scientific words have meanings and are usually formed by combinations of shorter words that refer to some characteristics of the animals under consideration. The word *Nemathelminthes* comes from two Greek words, *nema,* meaning thread, and *helmins,* meaning worm, and it is used in referring to a group of worms that are slender and thread-

like in shape.   Once you learn the meaning of the parts of the word, you have a description of the animals to which the word refers.   If you remember what the animals are like, you have a clue to the name of the group in which they are found.   Students find it easier to remember words of this nature than words without any etymological relation to the animals being studied.   Many of these roots of words will not be new at all, because a rather large number of our English words are formed in the same way by combinations of Greek and Latin roots.   For instance, there is the order of insects called the *Homoptera*.   The first part of the word comes from the Greek, *homos,* meaning "the same."   This same root is used in making a number of words which are already in common English usage, such as homogeneous, homosexual, homonym, and homocentric.

At first, the student may not be familiar with many of the roots used in making up scientific names, but these should be learned as they are taken up in the text, because these will be used in new combinations to form other words to be studied later.   If this is done, the learning of scientific names becomes easier as the study progresses.   Also, it is well to learn to pronounce the words as they are learned because words are remembered much easier if they are pronounced properly aloud.   It is a very poor policy for a student to attempt to learn scientific names by spelling alone.

If an animal happens to be large and frequently seen, it is very likely that it will have a **common name** as well as a scientific name.   A person untrained in biology could easily wonder why a scientific paper should use the name, *Turdus migratorius,* when referring to the common American robin which everyone knows.   Common names can be very misleading, however—the name robin was originally applied to a bird in England which is quite different from the American robin, although the two have a superficial resemblance.   The name dolphin is applied to a warm-blooded mammal of the whale family and is also the name of a cold-blooded fish. In many other cases the common name is used to apply to a large group of related animals without distinguishing between them.   For instance, the term "water dog" is applied indiscriminately to almost any kind of salamander.   Common names have a third disadvantage in that they often imply a relationship that does not exist.   Most people use the name "horned toad" for a short-tailed, dry-skinned animal which is abundant in Texas and some other southwestern states.   This animal looks somewhat like a toad, but is actually a lizard.   Such confusion of relationship is eliminated by the use of scientific names in order that other scientists may know exactly what is meant.   This does not mean that biologists go about "spouting" scientific names of common species of animals in their everyday conversation—common names are more satisfactory—but in scientific papers and reports where accuracy is necessary, the Latin names

must be used. There are many small and little-known animals which have no common names, and we must of necessity use scientific names if we are to speak or write about them.

Scientific names have further advantages—they are universal in nature and do not change from one language to another, as do the common names. Books and articles written in German, French, Spanish, English, or any other language all use the same scientific names. This is important because the scientists in one country must be able to interpret the discoveries made in other countries without the possibility of mistakes through translations. Scientific names have Latin endings and form their plurals in the same manner as Latin words. This sometimes is confusing if you have not studied Latin, but you should soon learn that the plural of *Amoeba* is *Amoebae* and the plural of phylum is phyla, to mention two common examples.

In the system of taxonomy which we use today, living things are placed into one of two great kingdoms—the plant kingdom, *Phyta,* and the animal kingdom, *Animalia.* (We should mention at this point that there are a few very small forms of life, such as the viruses, that do not fall into either of these groups.) Each kingdom is then subdivided into phyla. Each phylum consists of a group of organisms which have some important characteristics in common, but which are different from those in other phyla. By studying a typical member of each phylum it is possible to gain a comprehensive picture of the entire world of animal life in spite of the tremendous number of species that exist. Each phylum is broken down into classes, the classes are further divided into orders, the orders into families, the families into genera, and the genera into species. Each of these groups includes a smaller number of kinds of individuals than the one preceding it, until the species includes just one kind of animal, such as a dog, a horse, or a robin. Even species, however, may be subdivided into varieties, which may be called subspecies since we all know that there are different breeds of dogs, horses, and robins.

A better understanding of the system can be gained through a classification of some form of life with which you are familiar. Let us assume that you have a cocker spaniel dog named Becky. Now let us see how this animal would be classified. Of course we know that it would be in the kingdom *Animalia,* because it definitely is not a plant. As we look over the descriptions of the phyla of the animal kingdom we find that only one contains animals with a backbone. A dog's backbone can easily be felt through the skin of its back, so we know that it belongs in this phylum which is known as the *Chordata.* This phylum contains many diverse animals—frogs, fishes, snakes, birds, monkeys, and cows, to name a few, in addition to dogs. As we search for the proper class in this phylum,

we find that the class *Mammalia* includes all the animals that nurse their young by means of mammary glands, and since this is certainly the case in dogs, we place our dog in this class. Among the mammals, there is an order, known as the *Carnivora*, which includes animals that live primarily

Photo by Winchester

Fig. 6.2. A little cocker spaniel named Becky. It seems somewhat incongruous that such a little dog should have such a long classification. (See text.)

on meat and have long canine teeth for killing their prey. The dog falls in this category, even though the diet fed to it by man may be somewhat varied, so we place our dog in the order *Carnivora*. The carnivores include a number of families such as the *Felidae*, the cat family; *Ursidae*, the bear family; *Otariidae*, the sea-lion family; and the *Canidae*, the dog

family. We, of course, select the latter. We now have narrowed down our animals to a comparatively small group which includes the foxes, jackals, wolves, and dogs. There are only two genera in this family, the fox genus, *Vulpes,* and the dog genus, *Canis.* There are five well-known species in the genus containing the dog. There is the European wolf, *Canis lupus;* the timber wolf of North America, *Canis occidentalis;* the prairie wolf or coyote, *Canis latrans;* the jackal, *Canis aureus;* and our domestic dog, *Canis familiaris.*

Now our field includes only dogs, but there are quite a number of breeds that show considerable variation—collies, dachshunds, great danes, bloodhounds, and cocker spaniels are but a few of the many breeds. Our particular dog is a cocker spaniel. We can carry the classification to its final division by giving the name of the particular dog under consideration.   Arranged in outline form the classification would look like this:

Kingdom—*Animalia*
   Phylum—*Chordata*
      Class—*Mammalia*
         Order—*Carnivora*
           Family—*Canidae*
              Genus—*Canis*
                 species—*familiaris*
                    variety—cocker spaniel

To give the scientific name of a dog one would say *Canis familiaris,* thus including both the genus and the species names. The genus name is always capitalized, whereas the name of the species is always spelled with a small letter. The genus is a noun and the name of the species is usually an adjective which describes the noun. In this case, *Canis* means dog and *familiaris* means common or familiar.

When it is necessary or desirable, the name of the man who first described the species may be placed after the scientific name. As an example, the genus name for a frog is *Rana;* the bull frog is *Rana catesbeiana* and this species was first described by a man named Shaw. Hence, for utmost scientific accuracy the name of the bullfrog is written as *Rana catesbeiana* Shaw. Sometimes the name of the man who first described the species is placed in parentheses, as *Terrapene carolina* (Linnaeus) for the box turtle. This indicates that the species has been moved to a different genus after its first description.

The same species name is often used to describe a number of different genera; hence a species name when used alone does not refer to any particular one. For example, the catbird is *Dumetella carolinensis* (Linnaeus) and the white-breasted nuthatch is *Sitta carolinensis* Latham.
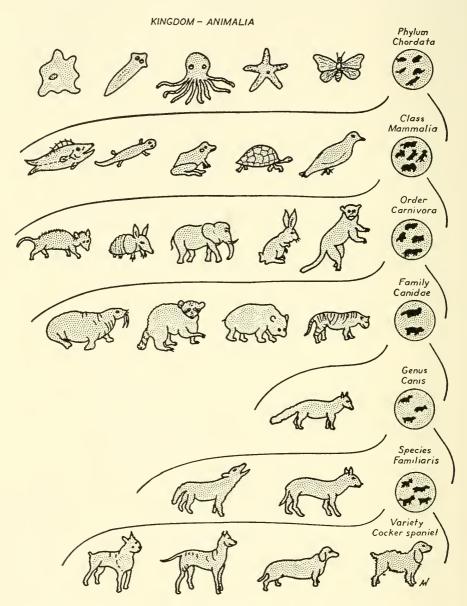
FIG. 6.3. Diagram of the classification of a dog. Starting with the entire animal kingdom, we gradually narrow the field to only dogs and to the variety of our subject.

Both of these were given the same species name because they were first reported in the Carolinas. Sometimes when one refers to a particular genus over and over again in a scientific paper it is permissible to use only the first letter of the genus after it has been written out in full in the first appearance of the word. Thus, you may see *T. carolina* for the box turtle or *R. pipiens* for the leopard frog.

The most important varieties of animals are sometimes called subspecies, and they usually exist only because they are isolated by some sort of barrier which prevents them from breeding with others in the same species. The red-shouldered hawks, *Buteo lineatus,* are divided into at least four subspecies in the United States. The largest race is the eastern red-shouldered hawk which is found east of the Rocky Mountains and north of the Gulf States. It is given the subspecies name of *lineatus.* Thus, the complete name of this variety is *Buteo lineatus lineatus.* It is separated from the slightly smaller and more reddish race west of the Rocky Mountains, the western red-shouldered hawk, *B. l. elegans.* To the southward, in Florida, north to South Carolina and along the Gulf westward into east Texas is the Florida red-shouldered hawk, *B. l. alleni.* This is a smaller and paler variety, apparently isolated from the more northern race by climatic barriers. In the Florida everglades and on the Keys is found the insular red-shouldered hawk, *B. l. extimus,* which is still smaller and paler and which is separated from the Florida red-shouldered hawk by climatic conditions. At some points where the ranges of these birds overlap slightly, there is inbreeding and hawks are found which cannot be clearly assigned to either of the two subspecies which have mingled together.

In domestic animals we can maintain varieties by a control of the breeding so that only members of the same variety are allowed to breed together. In this way we keep varieties pure. Our many pure breeds (varieties) of dogs bear testimony to the success of controlled breeding. It is easy to see what would happen without this restraint on breeding, when we see the mixtures of mongrel dogs that roam the streets of our cities. Each dog is a type unto itself with a pedigree which is likely to include many varieties.

Such mixing of different species does not occur for a number of reasons. For one thing, there is no sexual attraction between members of different species as a general rule. A male dog is not sexually excited by contact with a female cat who is in the phase of the reproductive cycle known as "heat." Hence, there is no mating between the two. Even if there were mating there would be no offspring. It is possible to artificially inject sperms from a dog into a female cat that is ready for breeding, but the sperms will not unite with eggs. There is a difference in the two spe-

cies which causes the reproductive cells to be incompatible. It might be mentioned at this point that there is a popular belief that a cat and a rabbit can be bred together to give an animal which is known as a "cabbit," but such a belief is false. This lack of sexual attraction and incompatibility of reproductive cells are sufficient to keep most species pure, but there are a few very closely related species of animals which do mate and produce offspring. A donkey and a horse are different species, but they will breed together and produce a mule; and a cow and an American buffalo may be bred to produce an offspring known as a cattalo. Both the mule and the cattalo are sterile, however, and the mixed species cannot continue beyond this one generation. This sterility is due to the differences in the chromosomes of the two species which have been crossed. In certain rare cases there may be offspring from the first generation hybrids —there are a few authentic cases of mules bearing colts for instance— but these are too uncommon to have great practical significance.

With these facts in mind we could say that different species either do not mate with one another or, if they do mate, they produce no offspring or offspring that are more or less sterile. Were it not for this barrier to crossing, think what a conglomeration of organisms we would have on the earth. Each individual would be a type unto itself—there would be no clear distinction between cats, dogs, and bears, or horses, cows, and sheep. Instead, there would be every gradation imaginable between animals that had no geographical barriers or other barriers to prevent crossbreeding.

This distinction seems to make it very clear that a species is a biological entity, and man needs only to discover the lines of division and give names to the species. There are many cases, however, where such a criterion cannot be applied. Many primitive forms of plants and animals do not have sexual reproduction; and, in these, the distinctions between species must depend entirely upon the judgment of workers based upon morphological and physiological features, since there can be no crossbreeding. Also, many species that have sexual reproduction have been named on the basis of morphological and physiological features because it has not been practical or convenient to observe the results of crossbreeding. Hence, we cannot cite any clear-cut universal criterion for the distinction of species which will apply in all cases—it is frequently human convention rather than biological entity that determines the distinction.

REVIEW QUESTIONS

1. Why is taxonomy a necessary part of biological science?
2. Who established the modern method of taxonomy? Describe his work.
3. What are the advantages of scientific names over common names?

4. List several familiar animals for which you have heard more than one common name. Give all the names you have heard for these animals.

5. Why is a species name never used by itself?

6. List the classification groups in their proper order.

7. Why are common names often misleading?

8. What prevents the mingling of varieties in nature?

9. How does the law of priority determine which of two names should be given an animal?

10. Give some examples of different species which may be bred together.

11. How are varieties of domestic animals maintained?

7

One-Celled Animals—Phylum Protozoa

The phylum Protozoa includes the one-celled animals. With only one cell for each body, it is evident that these animals must be quite small. Because of their small size they are not well known to the average person, since they can be seen in detail only by the comparatively few people who have access to a good microscope. With the aid of this valuable instrument, however, we find that these one-celled forms are quite numerous. A small pond of stagnant water may appear to be lifeless and uninteresting, but a drop of water from such a pond, when viewed under the microscope, becomes a miniature aquarium teeming with life of great variety. The beginning students of zoology never fail to marvel at the activities of this new world of life which the microscope reveals to them. Animals of many shapes and sizes dart back and forth; others move sluggishly across the field of vision; some smaller forms may be ensnared and devoured by larger forms; life in all its complicated reactions and relationships goes on here as it does among the larger animals.

The protozoa are sometimes spoken of as the simplest forms of animal life, and certainly they are simple in body organization when compared with the complex body of a larger animal with its many different kinds of cells. On the other hand, it must be remembered that all forms of animals must carry out certain vital life processes, and all of these processes must be accomplished by a single cell in the case of the protozoa. In the multicellular forms of animal life there can be a distribution of tasks among the different cells—some cells can function in digestion, some in excretion, some in reproduction, etc. The one cell of a protozoan, however, must function in all of these activities. It must act as a nerve cell when it receives stimuli—it must function as a muscle cell when it reacts to the stimuli—it must produce all of the enzymes necessary for digestion—it must take care of its own ingestion, egestion, excretion, etc. In this sense then the protozoa must be considered as very complex organisms. A protozoan cell will be more complex physiologically than any single cell taken from a large animal such as man.

At first thought one might think that the protozoa could be of little economic importance—they are so small—how could their activities be of any great concern to man? They are, however, of considerable economic importance. Many of them serve as food for larger water animals which, in

turn, may be eaten by still larger forms and so on.   At the top of such a food chain we find many fish and other water animals that are an important source of food for man.   Also, we have obtained much valuable information through research with the protozoa.   There is one in particular, *Tetrahymena geleii,* which has come into prominent use in recent years.   Many of the nutritional requirements of this protozoan are the same as those of human beings and it is valuable, therefore, in nutrition research.   The role of various foods, the effects of poisons, etc., have been worked out on *Tetrahymena*.   In Chapter 1 we showed how it has been of value in cancer research.   Not all the protozoans are of benefit to man, however.   On the debit side of the economic ledger we find that some of the protozoans have accommodated themselves to a parasitic existence in man and other animals and cause tremendous destruction of life and health.   Some of the most serious human diseases, such as malaria and amoebic dysentery, result from protozoan infections, and the control of such diseases is one of our greatest medical problems today.

Protozoa with False Feet—The Sarcodina

Protozoans that fall in the class Sarcodina are characterized by the presence of false feet, **pseudopodia,** which are projections that are pushed from the body when needed and withdrawn after they have served their function.   Any part of the body may be extruded to become a foot and, when withdrawn, it loses its identity as a foot.   There is a genus known as *Amoeba* which serves as a good example of this group of protozoans. *Amoeba proteus* is the species most commonly studied in the laboratory, but our descriptions apply generally for the genus as a whole.   Amoebae may be found most abundantly at the bottom of fresh-water ponds and streams among the debris formed there by decaying vegetation that settles from the water.

When placed under the microscope, we can see that an amoeba is a naked bit of protoplasm surrounded only by its thin plasma membrane. It has no definite shape and is constantly changing as it adjusts to its surroundings.   It moves by pushing out a slender pseudopodium in the direction in which it is going.   Then the rest of the body flows into the pseudopodium.   This movement is made possible by changes in the sol-gel relationship of the protoplasm in different parts of the cell.   The inner portion of the protoplasm is more fluid than the outer portion, and a flow occurs when a weakness develops in the outer portion.   To illustrate, let us think of an amoeba at rest; all pseudopodia are withdrawn and the animal assumes a spherical shape.   Then a weakness develops in the thicker outer protoplasm, thinner protoplasm from the center flows

through this weak spot, and a pseudopodium is formed.   As this proto-
plasm spreads out at the tip of the pseudopodium it assumes more of the
gel consistency, for it now forms the outer portion of the protoplasm.
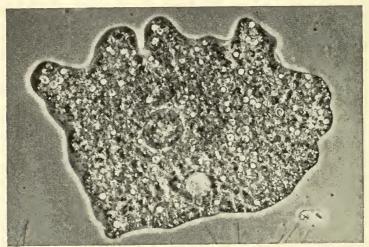
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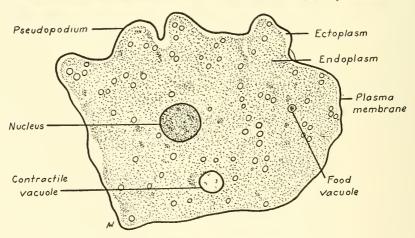
FIG. 7.1. Amoeba proteus. Top: photomicrograph of living organism. Bottom:
diagram of the same animal with labels of some of the structures that can be seen.

This, of course, is not a haphazard occurrence. The amoeba can con-
trol these changes in protoplasm consistency and thus control the for-
mation and direction of the pseudopodia.

Locomotion through the use of pseudopodia is called **amoeboid move-
ment,** but it is used by some other types of cells as well.   In fact, some

of the cells in your own body move by this method. These are the white blood cells which aid in the continual battle against the germs of infection. Some of these cells move through the tissues of your body in this manner ready to engulf any disease germs which may gain entrance.

Pseudopodia function in food getting as well as in locomotion. The amoeba obtains its nourishment from small plants and animals that share its habitat as well as from decaying bits of organic matter. The food is ingested by the interesting process of **engulfing.** Sometimes this can be seen under the microscope. The amoeba will approach the food, throw out a pseudopodium on either side of it, and then just flow around the food until it is inside the body. There is nothing like a mouth, or any certain place where the food must enter—it can be taken in at any point.

Although the food is now in the cell, the amoeba's problems of nourishment are by no means solved. We learned in Chapter 5 that food
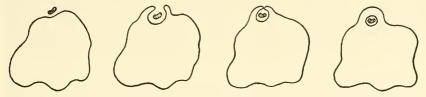

FIG. 7.2. Method of ingestion and the formation of a food vacuole in an amoeba.

must be digested before it is in a form which can be used. After the food of an amoeba is ingested it floats around in the cytoplasm surrounded by a thin membrane. This is known as a **food vacuole,** and it might be thought of as a temporary stomach in which digestion occurs. Enzymes diffuse into this vacuole and break the food down into soluble substances which can be utilized by the cell. After **digestion** there will remain an indigestible residue which must be eliminated. This is done by egestion, which is like ingestion in reverse. When digestion is completed the vacuole will move to the outer edge of the cell and burst through the plasma membrane, carrying the waste out.

Digested food can be used to build protoplasm within the amoeba and thus bring about growth through the anabolic phase of metabolism. The life processes of the organism require energy, and some of the food must be oxidized in the catabolic phase of metabolism to provide this energy. The oxygen which is necessary for this reaction diffuses through the plasma membrane from the surrounding water. There will be some dissolved oxygen in the water which supplies this need. (Boiling drives dissolved oxygen from water and amoebae will die rather

quickly if placed in water that has been boiled and cooled unless time is allowed for more oxygen to dissolve in it.) When oxygen combines with the digested food in catabolism and converts the potential energy into kinetic energy, three by-products result—carbon dioxide, ash, and water. The carbon dioxide is eliminated by diffusion through the plasma membrane, thus completing the process of **respiration.** The ash consists of various minerals which formed a part of the protein food of the amoeba—it is the so-called excretory waste. These minerals are in solution and pass out of the cell through the plasma membrane in a simple form of **excretion.**

Water is a necessary part of protoplasm, but only so much water is needed and any excess must be expelled. Water is produced in catabolism and it is ingested along with the food. Also, an amoeba living in fresh water will absorb water through its plasma membrane by osmosis. These three sources provide more water than is needed; if there were not some way of letting off the excess, the amoeba would very likely swell from this internal water pressure and might even burst. A **contractile vacuole** forms, however, and eliminates the extra water. Under the microscope this structure will appear as a spherical, clear body within the cytoplasm and, as you watch, it will grow larger and then suddenly disappear. The contractile vacuole originates near the center of the cell and receives the excess water of the cell. It grows larger as the water accumulates and migrates to the edge of the cell until, finally, there is only a thin membrane separating it from the outside. Then the membrane gives way and the water pours out. A new vacuole will soon form and the process is repeated. If amoebae are placed in water which has a concentration of dissolved minerals equal to or exceeding that of the protoplasm, no contractile vacuoles are formed. Some amoebae live in salt water, and these do not form contractile vacuoles normally. When some of these are placed in fresh water they will soon begin forming such vacuoles. These experiments establish the water-regulating function of the contractile vacuoles.

Under favorable conditions an amoeba will continue to grow until it reaches a certain size and then it undergoes mitosis and forms two cells of equal size. **Fission** is the term applied to such reproduction where two organisms of equal size are formed. It is **asexual reproduction** since there is no mingling of nuclear materials from different cells. So far as we know, the amoebae do not have any means of sexual reproduction. We can see from this description of reproduction that amoebae never grow old and die of old age—they may live indefinitely, even though split into many pieces. Actually, death is very frequent due to destruction by other forms of life and to extreme changes in environ-

ment, so we may say that amoebae die frequently by accident, but never from old age. An amoeba is thus potentially immortal—those that you see under a microscope have lived for millions of years through countless fissions.
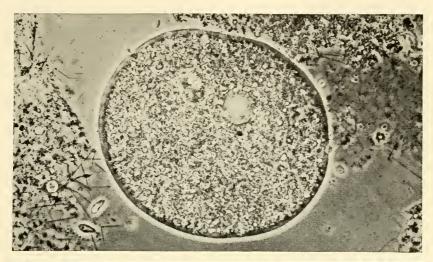
FIG. 7.3. Amoeba at rest and active. When at rest the animal tends to assume a spherical shape, but when moving it becomes considerably elongated.

Amoebae in the active state which we have been discussing are said to be in the **vegetative condition,** but, as such, they are very delicate things and easily destroyed. Some species of amoebae are known to

pass through unfavorable periods, such as the drying up of a pond, by developing a protective coating or **cyst** around themselves and reducing metabolism to the barest minimum necessary to maintain life. In this encysted form they are able to withstand such unfavorable periods and return to the vegetative state when conditions become normal again.
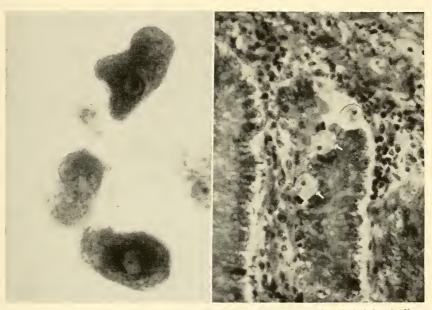
Amoebae display **irritability** even though they have no distinguishable areas of sensitivity. They will move away from a strong light source; this can be seen by viewing them under the microscope while shining a light from one side of the slide. Also, it is demonstrated by the fact that they are most abundant in the darkest portions of laboratory culture jars. They will react to various chemicals, moving toward some that attract them and away from others that repel them. They can distinguish between food material and other matter in the water; they engulf only that which they can use as food. They will actively pursue small water animals in an effort to capture them for food. They respond to heat and cold, always moving to the area of the water which is nearest their optimum temperature. They respond to vibrations in the water by pulling in extended pseudopodia. In these various reactions to their environment these single cells display sensory perceptions akin to those of the highest forms of animal life. Senses similar to touch, taste, smell, sight, temperature sensitivity, and even hearing are represented in these perceptions.

There is another genus in the Sarcodina which is amoeba-like in its body form. This is the genus *Endamoeba* which is so named because it lives within the body of other forms of life. The first species of the genus that we will consider is *Endamoeba coli,* which lives in the body of man and other vertebrates. This organism may be found in the colon (large intestine) of about half of all people, but fortunately it is harmless, since it feeds on the indigestible food or feces which passes through the colon. It is considerably smaller in size than *Amoeba proteus* and somewhat more sluggish in its reactions.

A closely related species, *Endamoeba histolytica,* has developed the habit of attacking the lining of the intestinal wall, and thus it becomes a serious parasite of man. When these organisms are in the intestine of man, they attach themselves to the cells and secrete a tissue-dissolving enzyme that destroys the cells and permits the *Endamoebae* to go deeper into the wall of the intestine and destroy more cells, and so on until they may produce a serious ulceration of the colon. In extreme cases this may cause perforation of the wall of the colon, liberating millions of bacteria, which are always present in a human colon. These pass out into the body cavity and set up an infection known as peritonitis which may result in death. Fortunately, there is a tough muscular layer in the intestine that normally

checks the penetrations of these organisms and thus prevents such serious results.

The disease caused by this infection is known as **amoebic dysentery.** The irritation of the colon usually causes a person to have extreme diarrhea accompanied by general weakness of the body. Examinations of the watery stools reveal thousands of the endamoebae in the active vegetative state. Also, many of the cells will be seen to have formed cysts by means of which the disease may be spread to other persons. Cysts

FIG. 7.4. *Endamoeba histolytica*, pathogenic protozoan which causes amoebic dysentery Left: active forms found in the stools of an infected person. Right: section of the large intestine of a person who died of amoebic dysentery. Three endamoebae can be seen in the center of the photograph.

are produced from the vegetative cells by the elimination of water which concentrates the protoplasm and by the formation of a protective cyst wall around the outside. The vegetative cells die rather quickly after they leave the protective warmth and moisture of the body, but the cysts can live a much longer time.

The cysts may be spread from one person to another through contaminated food or drinking water. The food may be contaminated by flies that have contacted fecal material from infected persons, or by food handlers that harbor the organisms in their bodies. Many persons

may carry these organisms in their intestines without showing any symptoms of the disease. In such a person a balance has been struck between the virulence of the organism and the resistance of the body, so that neither is able to overcome the other; yet the parasites are able to live and produce their cysts which may infect others. Drinking water may be contaminated from sewage seeping into surface wells or streams which are used as drinking water without proper purification. There was even one famous case where confused plumbers made the wrong connections in a hotel and allowed some sewage to get into running ice water in the hotel rooms. Many cases of amoebic dysentery resulted from this mix-up.

There are different strains of *Endamoeba histolytica* which vary in their effects on the body. There are some which are so mild that many persons are infected without knowing it. About 5 to 10 per cent of the people of the United States carry this organism. In tropical countries the percentage of infection is much higher, and serious symptoms may follow an infection. Our soldiers who were held prisoners in Korea were almost 100 per cent infected due to the poor sanitary conditions under which they were forced to live, and many died of the disease.

Any organism that causes a disease is known as **pathogenic.** *Endamoeba histolytica,* therefore, is a pathogenic protozoan. We will study several of these in this phylum, and it will help the student to be sure that he knows the name of each one studied, the disease it causes, the symptoms of the disease, and the means of spread from one person to another.

There is a third species of endamoeba that we will mention before we close our discussion of this genus. This is *Endamoeba gingavalis* which is found in the mouths of as many as 70 per cent of the population. They are especially abundant around the base of the teeth where they join the gums. If you scrape some of the material from this region of your own mouth and stir it up with a 1 per cent salt solution and keep the slide warm while studying it under the microscope, you are very likely to find that you are harboring this organism in your own mouth. It is more sluggish than the free-living amoebae, but you can see them throw out broad pseudopodia. Human customs permit this organism to spread from mouth to mouth in the vegetative condition and it is not known to produce cysts. They are not generally pathogenic, but there is some evidence that they may play some part in the damage done by the disease of pyorrhea. For the average person with a healthy mouth, however, there is no need to worry about the presence of these organisms and, human nature being what it is, there is little likelihood that we shall ever be able to control their spread.

Protozoa with Flagella—The Mastigophora

The members of this class have a more definite shape than the Sarcodina and are characterized by the presence of a whip-like attachment known as a **flagellum.** The flagellum is used in swimming—some genera, like *Euglena,* use it to pull themselves through the water, beating it down to
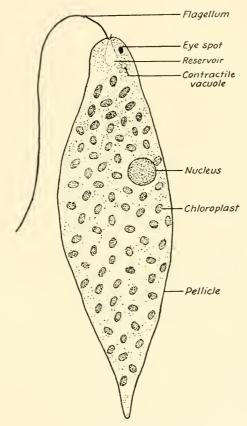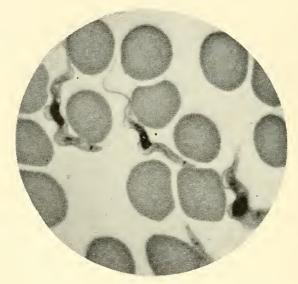
FIG. 7.5. Euglena viridis. This unusual organism has both plant-like and animal-like characteristics.

their sides as they go; while others, like *Trypanosoma,* use it as a tail to push themselves along.

A typical example of this class is *Euglena viridis.* When you look at one of these under the microscope you may be surprised to find that this animal contains chlorophyll within **chloroplasts.** This green substance is usually found only in plants, and for this reason euglena is sometimes

classified as a plant. This state of affairs is indicative of the thin line
of distinction which separates the two great kingdoms of living things
in their elemental forms. It is true that euglena has chlorophyll and
can manufacture its food, as do most plants; but further study shows
that it can live in the dark by absorption of nutrients that are present
in the water. This indicates the presence of digestive enzymes which
are animal-like in nature. Since green plants do not typically have
such enzymes, euglena may be considered as an animal that has de-
veloped the plant-like characteristic of chlorophyll. Also, euglena can

Courtesy General Biological Supply House

Fig. 7.6. *Trypanosoma gambiense* in blood. Sufficient numbers of these in the blood
cause the disease of African sleeping sickness.

sometimes be seen moving about by "inching" along somewhat like a
measuring worm. This type of movement (euglenoid movement) is
animal-like in its nature rather than plant-like.

Euglena has a red **eyespot** near the flagellum. This is sensitive to
light and thus represents a localization of the light-sensitive portion of
the cell. By use of this sensory body the euglena is able to perceive
and move to areas where the amount of light is best for photosynthesis.
This can be very dramatically demonstrated if a culture jar containing
euglena is covered with black paper except for a small hole cut in the
paper. When the paper is removed there will be a green spot in the
culture where the hole in the paper allowed light to come through.

Practically all of the organisms will have migrated to this area, and their combined bodies will give the green color to the spot.

Euglena lives in fresh-water ponds and streams and carries out its respiration and excretion in the same manner as the amoeba. It also has a contractile vacuole located near the flagellum which expels excess water. It reproduces by longitudinal fission.

During recent years we have heard much about the **"red tide"** along the western coast of Florida. When viewed from the air, large areas of the water can be seen to have a brownish-red tinge, and within this area there may be millions of dead fish. Many of these are washed up on the beaches and create a serious problem of disposal. An analysis of the water in such areas has shown a heavy concentration

FIG. 7.7. A person with an advanced case of African sleeping sickness.

of a marine protozoan, *Gymnodinium brevis,* which is in the class Mastigophora. A quart of water taken from this area will contain as many as 60,000,000 of these small animals. When so abundant, the waste products from these organisms cause the surrounding water to become thick and slimy, and fish cannot survive in it. The "red tide" appears whenever certain conditions prevail that are very favorable to the growth of this protozoan. The red color is due to pigmented bodies within the cells. It is estimated that half a billion fish were destroyed in this way along Florida's west coast in 1947.

Some of the Mastigophora invade the blood stream of higher animals and cause serious diseases. Among the many scourges of humanity to be found in Africa is the dread disease of **African sleeping sickness.** This disease is generally caused by *Trypanosoma gambiense,* one of the Mastigophora that lives in the blood stream of man. It is spread through the bite of the tsetse fly, a blood-sucking insect which is very abundant in many sections of Africa. Death usually terminates untreated cases of

African sleeping sickness, but drugs have been discovered that will kill these organisms and effect a cure when properly used. There is a virus-caused form of sleeping sickness in the United States which afflicts domestic animals (especially horses) and sometimes human beings. This should not be confused with the protozoan-caused African sleeping sickness.

There is another species of this genus, *Trypanosoma brucei,* that infects domestic animals and, in sections of Africa where the tsetse flies abound, it is impossible to keep such animals. Wild animals, such as zebras and antelopes, serve as carriers of this parasite without themselves being seriously affected by it, but death usually follows infection of horses, cattle, and pigs.

Dumdum fever or kala-azar is a serious disease in India, northern Africa and parts of South America. It is caused by a torpedo-shaped flagellate, *Leishmania donovani,* which causes enlargement of the liver and spleen as well as numerous sores on the skin. This often fatal disease is spread from person to person by sandflies. Great epidemics of kala-azar occurred in parts of India from 1890 to 1900 which decimated whole villages, and only in recent years has it been brought under control. This is one of the parasites which it was feared might be introduced into our country by returning veterans, since we have a sandfly which might transmit the organisms. Fortunately, careful watch over those infected with *Leishmania* has prevented this catastrophe.

There are several other less dangerous flagellates that often inhabit some part of the human body. One called *Trichomonas vaginalis* has its home in the human vagina, where it is usually benign, but may cause inflamation under certain conditions. Another species of *Trichomonas* lives in the tartar of our teeth; and a third, in the human intestine. There is another protozoan in this class which is rather large and bears several flagella. It is *Giardia lamblia* which has been found in 15 per cent of all human beings. It lives in the large intestine and sometimes causes a type of diarrhea which is known as giardiasis. It is difficult to eradicate and infections may last for years.

Spore-bearing Protozoa—The Sporozoa

The members of this class are all parasitic and produce spores as a part of their reproductive life cycle. Spores are small, asexually produced reproductive bodies that are usually quite resistant to unfavorable surroundings. Many plants produce spores, but only this class of animals uses this means of reproduction. There is only one genus in this class that infects the human body; but this one, *Plasmodium,* is a very serious pathogenic protozoan because it causes the disease of **malaria.** The

word "malaria" comes from two combined words meaning "bad air," a derivation that goes back to a time when the disease was attributed to the damp night air. We now know that it is the mosquitoes which are likely to be out in the night air that spread malaria. This is one of the best understood, yet one of the most destructive, diseases in the world today. We know how it is spread, how to treat it successfully, and how to prevent it, but it still ranks as the most serious infectious disease on our globe. Millions die from it each year, and many other millions are incapacitated by it. There are large sections of the world which are practically uninhabitable by white persons because of it. Our armed forces in the South Pacific found malaria a more serious enemy than human enemies. Large numbers of highly trained fighting men died or were disabled by this disease without ever going into action. We were successful in our operations in this region only because of the splendid work done by the entomologists and medical men in preventing and combating the infection.

At one time there were large sections of our own country where malaria was very prevalent, but today the spread of this disease has been reduced to the vanishing point in the continental United States. In spite of new cases being brought in from foreign countries, the vigorous program of the public health departments plus the prompt use of new anti-malarial drugs keeps the disease suppressed.

There are several types of malaria caused by different species of malarial parasites, but the one most prevalent and once common in our southern states is tertian malaria, which is caused by *Plasmodium vivax*. The word "tertian" means third, and this name was chosen because the chills and fever tend to reappear every 48 hours. By an old Roman method of reckoning, it was customary to count the day that something happened as the first day, the day following as the second, and the day following that as the third. Thus, even though the chills were only two days apart, they were said to recur on the third day.

Infection in a person may result through the injection of spores that are present in the saliva of an infected mosquito. The injected **sporozoites** enter cells lining the capillaries of the liver, spleen, and other internal organs. There they multiply for about a week or ten days and then break out into the blood stream where they attack the red blood cells. Each sporozoite may enter a red blood cell. There it rounds itself up into a ball with the nucleus at the edge and a vacuole in the center that makes it look like a signet ring. This is called the **signet-ring stage.** It gradually fills in the inside of the ring and takes on an amoeba-like form that now fills the center of the red blood cell. Then it breaks up into between 15 and 20 spores, the **merozoites.** The

weakened cell then bursts approximately 48 hours from the time it was first invaded and liberates the merozoites into the blood plasma. Each of these spores then finds another red cell and the cycle will be repeated until literally billions of red cells are being destroyed every 48 hours.

The first symptoms of the disease appear within about two or three weeks after infection. When the many red cells burst at about the same time, liberating the spores and the accumulated wastes of the parasites, the body reacts to this poison with a chill. This is followed
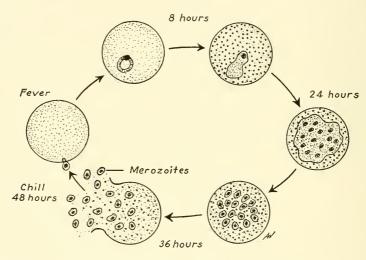

FIG. 7.8. The cycle of tertian malaria in human blood cells. At the extreme left a merozoite is shown entering a red blood cell. This then forms the signet ring stage, followed by the amoeboid form and the appearance of pigment granules in the red blood cell. This is followed by the presegmenter stage where there are many nuclei in the parasite. Then, in the segmenter stage, the parasite breaks up into merozoites. Finally, the blood cell breaks open liberating the merozoites and the cycle begins again. The hours indicated represent the approximate time from the beginning of the chill.

by a rather high fever as the body speeds up metabolism to counteract the chill. Then, as the fever subsides the person will feel better, but will be weakened and anemic due to the loss of red blood cells. Without treatment, the same cycle will be repeated 48 hours later, and so on, until the person dies, or his natural body resistance brings the disease under control. There are many malarial carriers that harbor the parasites and serve as a reservoir of infection, yet do not show serious symptoms themselves.

This cycle spreads the parasites within the body; yet, if the parasite is to survive, it must have some means of spread to other persons,

because all persons must die sooner or later, taking all their parasites to the grave with them. We have already mentioned the mosquito as the agent of spread. Just any kind of mosquito, however, cannot serve this purpose—it must be a female *Anopheles* mosquito. It must be a female because male mosquitoes are vegetarian in their diets and suck the juices of plants. The females also suck such juices, but will take blood when they can get it. It must be an *Anopheles* mosquito because this is the one in which *Plasmodium* can continue its life cycle and, as the physiology of other mosquitoes is different, the parasite cannot live in their bodies.

Cyst producing spores
Ameboid zygote
Sperm and egg uniting to form zygote
Egg (from female gametocyte)
Sperm (from male gametocyte)
Spore going to salivary glands

Salivary glands

Proboscis

Skin surface
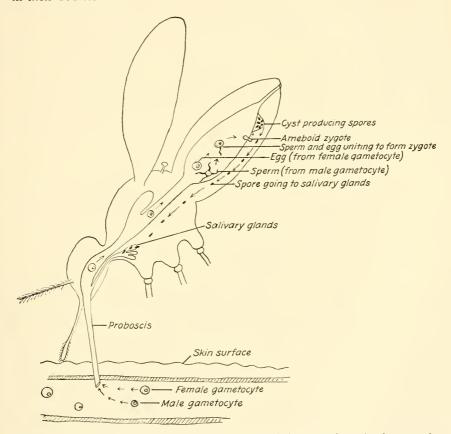
Female gametocyte

Male gametocyte

Fig. 7.9. Cycle of the malarial organism in the Anopheles mosquito. As the mosquito sucks blood from an infected person, some male and female gametocytes are taken in. In the mosquito's stomach these form eggs and sperms. An egg and a sperm unite and form a zygote which then becomes amoeboid and makes its way through the stomach wall. It encysts on the outside of this wall and produces many sporozoites. These migrate to the salivary glands and may be injected into another person along with the saliva. The entire cycle requires about twelve days.

Certain of the merozoites grow in the plasma of the blood and become male and female **gametocytes** which may function in sexual reproduction which takes place in the mosquito's body. If the proper kind of mosquito bites and sucks up at least one of each kind of gametocyte, the cycle continues in the mosquito's stomach. The female gametocyte becomes an egg without much change, but the male gametocyte gives off from four to eight slender sperms which break off and swim to the egg. One unites with the egg and produces the **zygote.** This zygote be-
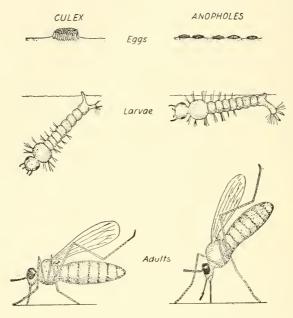

FIG. 7.10. Diagram showing how the Culex can be distinguished from the Anopheles mosquito by body position and egg distribution in three stages of the life history.

comes amoeboid in nature and squeezes itself between the cells of the stomach wall and forms a cyst on the outside of this wall. The zygote divides within this cyst until large numbers of spores, the sporozoites, are produced. The cyst then breaks and the sporozoites migrate through the body cavity, some of them reaching the salivary glands of the mosquito. This cycle requires about 10 to 12 days, so a mosquito is not infective until at least this long after it has bitten a person with malaria. Once it becomes infective, however, it is likely to remain so for its entire life, which may be several months. Each zygote produces about 10,000 sporozoites.

The cycle is completed when the mosquito bites another person. When the mosquito bites she injects a little saliva into the wound which prevents the blood from clotting. This saliva will carry the sporozoites into the body of the person which she is biting, and the cycle begins again.

Malaria control is one of the major health problems of the world because of the widespread occurrence of this disease. There are many regions of the world which are rich in resources, but remain undeveloped because of the prevalence of malaria. Many of these are being opened to development by a program to fight malaria. Since all mosquitoes must pass the first part of their lives in water, most means of control start there. Swamps can be drained or oiled and other bodies of water can be kept well supplied with minnows which eat the eggs, larvae, and any adults which may alight on the water. Sprays, such as DDT, will help eliminate any of the adults that manage to survive. These measures coupled with a campaign to find and treat those persons carrying the malarial parasite will do much to eradicate the disease.

Protozoa with Cilia—The Ciliata

Members of this class are found very abundantly in the water of ponds and streams which is rich in decaying organic matter. They can usually be cultured rather easily in the laboratory by placing some dead grass or other leaves in pond water and allowing the mixture to stand for a week or two. As the water becomes turbid with suspended particles of decaying matter, the ciliates will usually be rather abundant. All members of this class bear **cilia** on their bodies. Cilia are very small hair-like structures which can beat back and forth in locomotion. By controlling the beating of the cilia these organisms can move in any direction without changing their body position.

Paramecium is a good representative genus of this class which is usually selected for laboratory study to illustrate a complex protozoan. A number of different species are commonly available, but *Paramecium caudatum* is probably used more than any other. It is found abundantly in many ponds which are rich in organic matter. It is a slipper-shaped animal with its body covered by a tough, yet flexible, **pellicle.** This pellicle enables the paramecium to bend its body, but it will return to it original shape when it relaxes the bending force. The plasma membrane lies under the pellicle. Cilia are embedded in the pellicle and are arranged in the form of a spiral down the longitudinal axis of the animal. This causes the paramecium to revolve and take a spiral course through the water when swimming. A single animal will have

about 2,500 cilia on its body. There are also tiny bulbs of a gelatinous liquid, the **trichocysts,** embedded in the pellicle. When irritated the paramecium may squirt this liquid out into the water where it hardens and forms sticky threads which act in a protective capacity—enemies are likely to get tangled up in these threads and thereby be rendered harmless.

Food vacuole

Anal pore

Contractile vacuole

Mouth pore

Oral groove

Micronucleus

Macronucleus

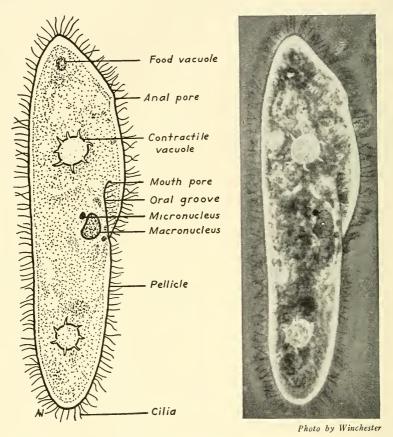Pellicle

Cilia

Photo by Winchester

Fig. 7.11.   Paramecium caudatum.   Right: a photomicrograph of a living form.   Left: diagram identifying some of the structures which can be seen.

Many of the life processes of paramecium are similar to those found in amoeba, but there are certain differences which are noteworthy. For one thing, there is a definite opening for ingestion and another for egestion. The entire process of **digestion** can be demonstrated if we place some yeast cells stained with congo red on a microscope slide with some paramecia. Under the microscope we can see the masses of

red yeast cells being caught up by cilia which line the oral groove and being forced through the gullet into the body. There the yeast cells are rounded up into food vacuoles. As time passes the color of the yeast within the vacuoles will change from a deep red to blue. This indicates that enzymes have passed into the vacuoles and are digesting the yeast. The color change means that the contents have changed from alkaline to acid. A similar change takes place in the human
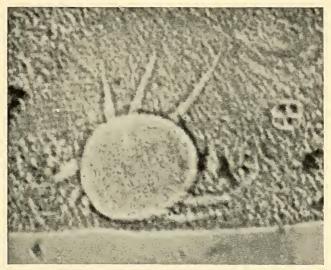

Photo by Winchester

FIG. 7.12. Small portion of living paramecium greatly enlarged to show a contractile vacuole and its surrounding rays.

stomach. The vacuoles become smaller as the food is digested and the soluble part diffuses out into the protoplasm. When only an indigestible residue remains it will be expelled through the anal pore which lies slightly below the gullet. This pore is quite small and cannot be seen except when the animal is in the act of egestion.

There are two **contractile vacuoles** in *Paramecium caudatum,* and these remain in a fixed position. There are radiating canals that bring water to the vacuoles from other parts of the cell. When the vacuoles become full they will contract rather quickly and force the water to the outside. There is a small pore which connects with each vacuole for this purpose. It requires only about fifteen seconds for a contractile vacuole to fill and empty its contents.

Respiration and **excretion** are carried on by diffusion through the plasma membrane as in amoeba. The pellicle is highly porous and offers no hindrance to this diffusion.

In stained specimens of *Paramecium caudatum* two nuclei can be seen—a larger **macronucleus** and a smaller **micronucleus**. We do not know just why there should be such a division of the nucleus in these animals, but it is quite clear that the micronucleus contains the genes of heredity. It can be seen undergoing mitosis when it divides, but the macronucleus does not show this process.

Reproduction is by transverse **fission** which is accompanied by a division of each of the nuclei. This may often be seen in the laboratory since, under favorable conditions, it will occur about every 10 or 12 hours and requires about an hour for the completion of the process. Of course such a rate of reproduction cannot continue very long, for all the oceans of the world would be filled with paramecia within a year if it did. Their reproduction slows down as waste products accumulate in the water, as the food becomes exhausted, as temperature becomes unfavorable, or as other unfavorable factors come into play.

There is also a form of sexual reproduction known as **conjugation** which takes place in paramecium. This is best understood in *P. caudatum*. Two animals come together and unite at their oval grooves. There then follows some interesting changes in the nuclei. The micronucleus divides twice and the macronucleus disintegrates. This leaves four micronuclei in each paramecium. Then three of the micronuclei of each disintegrate, and the one remaining divides into a larger immotile micronucleus and a somewhat smaller motile micronucleus. The small one of each moves across a connecting protoplasmic bridge and unites with the larger micronucleus of the other animal. Then the two animals separate. So far there has been no actual reproduction, but there will be two divisions immediately following conjugation accompanied by some nuclear phenomena which are shown in Fig. 7.13. Conjugation is not necessary for the continuation of the species in paramecium, for one worker isolated a single individual and followed 15,000 generations of descendants over a period of 25 years without conjugation ever occurring. It does, however, accomplish an important objective. In conjugation there is a trading of genes between two individuals. This gives new combinations of hereditary traits which results in a variety in the descendants that would not be possible without such a genic exchange. Variety is important, because through variety there can be a natural selection of the most fit individuals which will continue the propagation of the species.

Although there are no morphological distinctions between the two paramecia which undergo conjugation, it has been shown that there is some physiological difference which is akin to sex. Just any two paramecia cannot conjugate. There will never be conjugation among the descendants of a single individual—the conjugating animals must be of different mating types. We cannot call one of them male and the other female, however, for in some species of paramecia several different **mating types** have been found and any one can conjugate with

Two paramecia unite

Micronuclei divide macronuclei disintegrate

Micronuclei divide again. 3 of each 4 disintegrate

Remaining micronuclei divide into male and female portions

Male portions move into opposite cells

Exit one paramecium

Animals seperate male and female elements fuse

Fused nucleus divides 3 times giving 8 micronuclei

4 form macronuclei; 3 disintegrate

Cell and the micronucleus divide

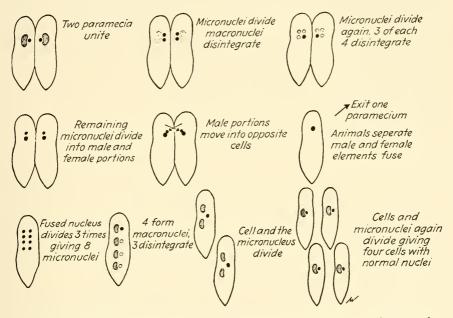Cells and micronuclei again divide giving four cells with normal nuclei

FIG. 7.13. Conjugation in paramecium. These diagrams show the rather complex series of nuclear divisions, disintegrations, and fusions which take place.

several of the others. Still we can think of these as a beginning of the physiological differences which distinguish sexes in higher forms of animal life and which cause an attraction between those of opposite mating types.

There are quite a number of other genera of ciliates, including *Tetrahymena* which we mentioned in the early part of this chapter. There is one species in this class that is parasitic on human beings and it also lives in pigs and chimpanzees. This is *Balantidium coli* which may be found in the intestine of about 80 per cent of the domestic swine in some localities. It is a large ciliated organism which forms numerous round, thick-walled cysts which occasionally find their way into the human di-

gestive system. Here they lose their thick walls and start to multiply. They penetrate the inner lining of the intestine and often form ulcers which cause an attack of dysentery. Infected persons, if not promptly treated, pass numerous cysts which may spread the disease.

Stalked Protozoa—The Suctoria

There are a number of protozoans which are ciliated in the early stage of their life, but lose the cilia and become attached to some object by means of a long stalk when they grow older. They capture food, which often consists of other protozoans, by means of tentacles. Some of these tentacles have small suction cups on the end, which characteristic gives the class its name. Young animals are formed from a portion of the parent cell. They develop cilia, swim around for a time, and then form a stalk and turn into the adult form. This is not usually considered as an important class of the Protozoa.

Classification of the Protozoa

We have now surveyed some representative forms in the phylum Protozoa. In order to keep up with the classification of the animal kingdom as we go along we will list the important classification groups at the close of each chapter, together with the derivation of the words when such derivations are of value in learning the words. This will give a systematic outline of the animals studied in each chapter dealing with the survey of the animal kingdom.

Phylum.   Protozoa (Gr. *protos,* first ; *zoon,* animal ; refers to the fact that these are the first or simplest animals).

    Class A.   Sarcodina (Gr. *sarx,* flesh ; refers to the false feet made from the animal's flesh).

        Genus 1.   Amoeba (Gr. *amoibe,* change ; refers to the Amoeba's power to change its shape).

           species a.   proteus (the name of an old Greek sea god that could change his shape).

        Genus 2.   Endamoeba (Gr. *endon,* within ; *amoibe,* change ; refers to the amoeba living within another animal's body).

           species a.   coli (En. *colon,* large intestine).

           species b.   histolytica (Gr. *histo,* tissue ; *lysis,* dissolve ; refers to the tissue-dissolving properties of this species).

           species c.   gingivalis (L. *gingiva,* the gums of the mouth ; refers to the habitat of this species on the gums).

Class B. Mastigophora (Gr. *mastix,* whip; refers to the flagellum; and *phera,* bear).

    Genus 1. Euglena (Gr. *eu,* good; *glene,* pupil of the eye; refers to the fact that this animal has a small eyespot near the point where the flagellum joins the body).

        species a. viridis (L. *viridis,* green).

    Genus 2. Trypanosoma (Gr. *trypanon,* auger; *soma,* body; refers to the auger-like body that these animals possess).

        species a. gambiense (*Gambia,* a political subdivision of Africa where this species is found).

        species b. brucei (named in honor of James Bruce, Scottish traveler and scientist, who showed that sleeping sickness of domestic animals in Africa was caused by this species).

    Genus 3. Leishmania (Sir Wm. Leishman, a British surgeon).
        species a. donovani (Edward Donovan, English pharmacist).

    Genus 4. Trichomonas (Gr. *tricho,* hair; and L. *monas,* a unit).
        species a. vaginalis (L. *vagina,* a sheath; refers to human vagina).

    Genus 5. Giardia (Alfred Giard, French biologist).
        species a. lamblia (William Lambl, a Bohemian physician).

Class C. Ciliata (L. *cilium,* eyelid; the cilia on some forms resemble the hairs on the eyelid).

    Genus 1. Paramecium (Gr. *paramekes,* oblong; refers to body shape of this genus).

        species a. caudatum (L. *caudata,* having a tail; refers to the pointed posterior).

Class D. Sporozoa (Gr. *spora,* seed; *zoon,* animal; spore-producing animals).

    Genus 1. Plasmodium (Gr. *plasma,* formed or moulded; has come to refer to the viscous material of a cell; *eidos,* like; applied to organisms that change their form during their life cycle).

        species a. vivax (L. *vivax,* long lived or vivacious; refers to the long life and vigor of these animals in the human body).

REVIEW QUESTIONS

1. What is the distinguishing characteristic of the class Sarcodina?
2. Describe locomotion in the amoeba.
3. Can you reason out any advantages of amoeboid movement among the white blood cells of the human body?
4. Describe the method of digestion in the amoeba.
5. List the products that enter and leave the amoeba through diffusion.
6. What is the function of the contractile vacuole?
7. The amoeba grows most rapidly at a temperature of about 68 degrees. Would you expect reproduction to be most rapid at this temperature also? Explain.

8. How is the amoeba able to withstand unfavorable environmental conditions?

9. What is the distinguishing characteristic of the class Mastigophora?

10. What is meant by the term pathogenic? Name two pathogenic protozoa, the diseases caused by each, and the means of spread of each disease.

11. How does euglena differ from most other forms of animal life?

12. Explain the difference in locomotion of euglena and trypanosoma.

13. Describe two uses of the cilia in paramecium.

14. What results would you expect if the macronucleus were removed from paramecium?

15. What are trichocysts and how are they used?

16. Why would you not expect conjugation among a group of paramecia that had descended from a single individual through repeated fission?

17. How do the contractile vacuoles of paramecium differ from those of the amoeba?

18. Trace the plasmodium cycle within a human body.

19. Trace the plasmodium cycle within the mosquito's body.

20. Discuss methods of malaria control.

21. Why is spore production an unusual characteristic of animals?

22. Name the four classes of Protozoa, the distinguishing features of each class, and representative genera under each.
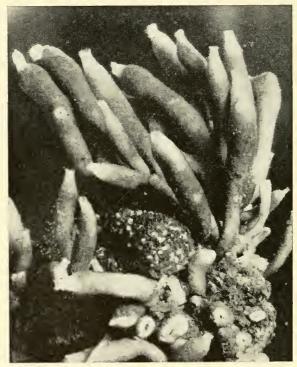
8

The Sponges—Phylum Porifera

Porifera, the name of this second phylum, means to bear pores; and all members of it have tiny holes perforating their bodies, so the name is very appropriate. Commonly we refer to these animals as sponges. For a long time they were thought to be plants because of the fact that they spend most of their lives attached in one place and are not active in the sense that most animals are. Morphological studies, however, have definitely placed them in the animal kingdom. The bath sponge, with which everyone is familiar, is a common member of this phylum and, because of its porous nature, it is able to hold large quantities of water. However, the bath sponge is not a typical genus of this phylum, so we will pick another genus, *Scypha,* as a type animal.

A Simple Sponge

Scypha is a small vase-shaped sponge about an inch in height which lives attached to rocks or other solid objects in shallow salt water. It lives only in salt water and thus may be spoken of as a **marine** animal in contrast to a fresh-water animal. Examination with a hand lens or microscope will reveal the many tiny **pores** that are found all over the body. Also, it will be noticed that the body is covered with sharp spines, called **spicules,** that serve to support the softer parts of the body and, therefore, we might think of them as forming a primitive sort of skeleton. These spicules are composed of calcium carbonate. Because they are sharp and project out all over the body, they also act as a discouragement to any animal that might wish to nibble on them. At one end of the body you will see a large opening which is called the **osculum;** at the other end is the **point of attachment.**

Scypha has an interesting method of **ingestion;** cells which line the canals running through the body bear **flagella** which keep a constant current of water flowing into the pores, through the canals into the **cloacal cavity** in the center, and, finally, out through the osculum. This water contains disintegrating bits of organic matter and small living organisms which may be used as food; the cells engulf this food as it passes by. We might compare this to a cafeteria where the patrons go in and

sit down while a moving belt carries the food past them and they reach out and help themselves to that which appeals to them. The cells which bear the flagella have a collar around the base of the flagellum so that, in beating, the flagellum will not drive away food particles which the cell needs to ingest. These are called **collar cells** because of this characteristic. **Digestion** is still intracellular as in the protozoa, and in **egestion** the cells expel the residue into the water flowing past, so that the entire

Courtesy General Biological Supply House

Fig. 8.1. A cluster of scypha. New individuals arise from old through budding; thus eventually a large cluster of these sponges may be found in one spot.

process is still very much the same as in amoeba. With all this taking place, you can see that the sponge is really a very active animal after all, and a sponge only an inch or so long can draw as many as 45 gallons of water through its system in a single day.

Respiration is still by direct absorption of oxygen from the water by the cells and the giving off of carbon dioxide into the water as it flows past. **Excretion** follows the same pattern as each cell gives off these wastes into the convenient sewage system flowing past it. The excretory

products of the sponge seem to be repulsive to many forms of animal life and thus excretion becomes a form of protection from possible enemies.

Reproduction may be by two methods. The first is by **budding** and does not involve any union of gametes to form a zygote; so we may speak of it as **asexual,** meaning without sex. In this method a little bud appears near the base of an adult sponge, and this gradually grows to form a full-sized scypha. It may continue to adhere to the parent after

Courtesy General Biological Supply House

Fig. 8.2. Spicules of scypha. These calcified structures are distributed throughout the softer body parts for the purpose of support and protection.

reaching full size, and frequently colonies of many individuals may be seen that have arisen from one through budding. Sometimes they break off from the parent and form a new attachment, thus starting a new colony.

In **sexual reproduction** certain cells of the body become differentiated into **sperms** while others form **eggs.** As is true in all cases of sexual reproduction, many more sperms are formed than eggs, since the egg has to be larger in order to store food for the developing embryo, while the sperms need only food enough to enable them to swim to the egg.

Therefore, the sperm is much smaller than the egg, but, nevertheless, carries just as much weight in determining heredity because it carries just as much of the chromatin as is found in the egg.   In the sponge the sperms migrate to the egg and one of them will unite with it to form a zygote.   This begins to divide and forms a small larva with cilia that is able to swim about in search of a good place to settle down and grow
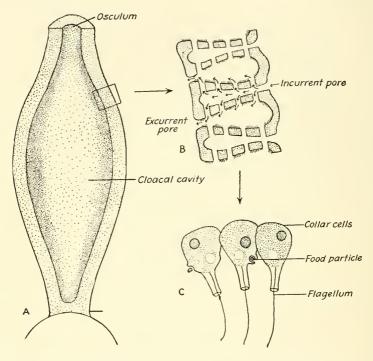

FIG. 8.3. Scypha, internal structure. A. Diagrammatic longitudinal section showing the vase-like structure of the body. B. Detail of small portion of the body wall showing course of the water through the pores from the outside to the cloacal cavity. C. Collar cells. The spicules are not shown in any of the drawings.

into an adult.   By this method the sponges achieve wide distribution so that the offspring will not congregate too close to their parents and be in competition with them for the available food supply.   Because both sperms and eggs may be produced in the body of one sponge, we call the sponges **hermaphroditic** animals as contrasted to the condition of higher forms where the two types of gametes are produced in separate individuals which are male and female animals.

Regeneration

There is another process which sponges can carry on that may be discussed in connection with reproduction. This is **regeneration,** which is not a normal means of reproduction, but on occasion may serve to produce new individuals and, at least, we may refer to it as an accidental means of reproduction. When a scypha is cut into two parts, each part will proceed to regenerate the missing piece so that two complete animals will be formed. The same will be true if cut into four parts and may even be carried so far that a small piece cut out of the animal will regenerate a complete new body.

We can demonstrate the remarkable powers of regeneration in sponges by forcing the pieces of a red sponge (*Microciona*) through heavy silk bolting cloth. This breaks the sponge into separate cells, or groups of very few cells, but these gradually clump together in the bottom of the dish and form numerous small sponges. In a short time the flagella of the collar cells begin to beat, and each clump becomes a functioning individual.

This great power of regeneration is gradually lost in the animal kingdom as the complexity of the animals increases. Because of the specialization of different parts of the body for different functions, the cells have to become more highly differentiated from the embryonic cells from which they came, so that the embryonic function of reproducing all types of cells is lost. For instance, the highly complex nerve cell of man has gone so far in adapting itself to its particular function that it is inconceivable that it could regenerate skin, bone, or muscle. The power is never completely lost, however, because, even in man, new skin cells can be regenerated to replace those destroyed; new bone and muscle cells are regenerated from injured bone and muscle tissue, and so on. The power seems to have reached its lowest ebb in nerve tissue, probably because it contains the most specialized of all cells. Cells of the brain and spinal cord can never be regenerated if destroyed; permanent insanity will result from destruction of a part of the brain by disease or injury. However, processes of the nerve cells that run from the brain and spinal cord to various parts of the body can be regenerated if the part containing the nucleus is not damaged and the regenerating process has something to guide it.

Scypha, on the other hand, has all of its cells very much alike and each carries on the various life processes, so that each cell has about the same power to produce all types of cells necessary to form a new animal as did the zygote or the embryo. Somewhere between these two extremes we find animals like the earthworm in which, if cut in two, the

front half can regenerate a new posterior half, but the posterior half cannot regenerate the anterior half. A little more highly specialized is an animal like the lobster which will be killed if cut in two, but which can regenerate a lost leg.
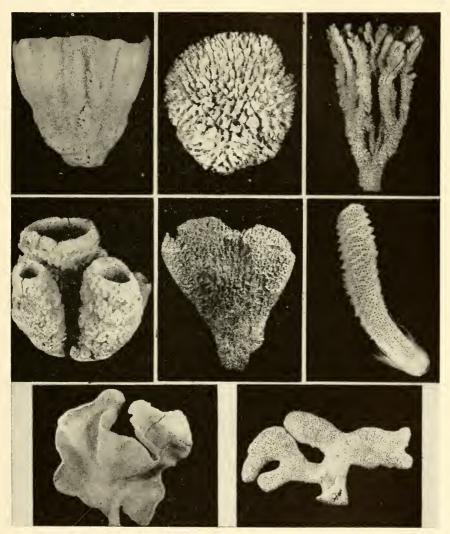
If this line of reasoning is correct (that differentiation of cells is responsible for the loss of the power of regeneration), we would expect the power to be greater in the embryos of higher animals before the cells become differentiated. Embryological observations show this to be true; an early embryo, even of a complex animal like man, has about the same degree of regenerative power as does the sponge. If broken into two parts each part will regenerate the lost portion and two complete individuals are produced instead of the one that would have been formed. The same may occur to give four individuals if broken into four parts, with the record number now standing at five. Higher numbers are lacking, probably not through any lack of regenerative powers of the embryo, but through a lack of sufficient room for development within the mother's body. With this in mind, it is easy to see how any of us might have been twins through a simple cleavage of our bodies in our early development. Thus, we can see that the distinction between the more complex and the simpler animals is merely one of degree of development. All start life at about the same level; all are one-celled animals in the beginning; some never get beyond one cell; some form an aggregation of similar cells such as scypha; some go on developing and the cells become highly differentiated to form a complex organism such as man.

The Metazoa

Since scypha has a body composed of many cells it is one of the **metazoa,** or many-celled animals, as compared to the protozoa, or one-celled animals. This term, metazoa, is not a phylum name, but is called a subkingdom and is used for convenience in referring to animals with many cells in their body in contrast to those with only one.

We might say that the protozoan cells are individualists—each cell does everything for itself and there is no limitation of action that must necessarily accompany a group organization. After any cell division, the two daughter cells break apart and form separate individuals. In the metazoa the cells remain together after cell division and in time will form a large group of cells where there can be a division of tasks and a specialization of the different cells for the tasks to be performed. All cells function in a way that benefits the entire organism. The metazoa, by living as a combined group of cells, usually attain a much larger size than the protozoans and have many other advan-

tages; yet, because of the specialization of the cells, the metazoan is doomed to death as these cells grow old and die. On the other hand, the protozoan is potentially immortal even though death may come often due to various circumstances which can destroy it. In the

Photos by Winchester

FIG. 8.4. Sponges grow in many different shapes and sizes. These are: Top row—grass sponge, *Spongia dura*, and finger sponge. Middle row—tube sponge, sheep wool sponge, and Venus flower basket. Bottom row—paper sponge, and crumbs of bread sponge.

metazoan, certain cells retain their power to form other types of cells, and these can serve in reproduction. Thus, new individuals are produced before the parents grow old and die.

Scypha is a very primitive animal, with little specialization of cells as compared with the higher metazoan animals. In many respects it is somewhat like a group of Protozoa stacked together with each living its own life, since the cells are not connected with nerves and the bottom half would not know it if the top half were crushed; yet it shows some specialization in the collar cells, reproductive cells, and others; and it does function as a unit in many respects. Hence, it is usually classed as a metazoan, but some prefer to set the sponges apart in a separate subkingdom known as the Parazoa.

Recent work by A. Whitely has shown that the step from one-celled to many-celled animals may be more narrow than we have previously believed. He took a group of protozoans, *Stentor coeruleus,* cut gashes in them and fitted them together at the cut regions. The animals fused together and became a multicellular unit. Not only did they unite in this fashion, but there actually began to be a specialization of cells. At one end of the mass of cells a head developed with a mouth which took in food for the entire group. When this head was cut off a new head was regenerated. This work shows how multicellular forms might have arisen from one-celled forms of life.

The Bath Sponge

There are a number of other genera of sponges, one of which may be found in fresh water; but, from an economic point of view, the bath sponge is more important than any of the others. If you were to see a bath sponge in its natural live state, you probably would not recognize it; it would look more like a slimy piece of raw meat than the sponge that you are accustomed to use in your bathroom or for washing your car. It is only after the living sponge has been taken out of the water and hung up in the air where the protoplasm dies and oozes out of the skeleton, and this skeleton is washed and bleached, that it resembles anything like the sponges that you are familiar with. The skeleton of the bath sponge does not have spicules as does scypha, else you would scratch your back as you scrubbed it, but has strong elastic fibers instead that make it tough and serviceable.

This type of sponge grows abundantly in warm tropical waters, and there is a very extensive sponge fishing industry centered around Tarpon Springs, Florida. Sponge fishermen go out in small boats and pull the sponges up from their attachments in the shallow water by hooks on poles.

In deeper water they go down in diving suits and gather them. The sponges are then hung up to rot and dry, later to be cleaned and bleached for market. When sponge fishing is carried on too extensively in a region, however, there is likely to be a scarcity, and it may be necessary to raise them as a crop just as a farmer would raise corn. Small pieces of living sponge are used as "seed" and are anchored to some solid attachment which is then sunk in shallow water and regeneration takes care of the rest. Within about three years of average growth a sponge will enlarge from one to six inches in diameter and will be ready for market.

The fisherman, while harvesting them, leaves a little piece remaining as he cuts them from their attachments and so has a perpetual crop once he gets them started.

Classification and Derivation of Words

Phylum Porifera (L. *porus,* pore; *ferre,* to bear; refers to the small pores which the sponge bears on its body).

Genus 1. Scypha (Gr. *skyphos,* cup; refers to body shape).

REVIEW QUESTIONS

1. What is the function of the collar on the collar cells of scypha?
2. Distinguish between egestion and excretion.
3. Is the osculum of scypha comparable to the mouth of more advanced forms of animal life? Explain.
4. Why is the egg always larger than the sperm?
5. What is an hermaphroditic animal?
6. What seems to determine the degree of regeneration possible in an animal? Explain.
7. Contrast the metazoa with the protozoa and tell why it is difficult to fit the sponges into either group.
8. How does the bath sponge differ from scypha to make it commercially valuable?
9. What is the function of the spicules?
10. Describe the process of budding in the sponges.
11. Of what advantage to the sponge is a motile larva?
12. Old age and a natural death were unknown until specialization of cells took place in the metazoa. Explain.

9

Two-Layered Animals — Phylum Coelenterata

This phylum name means "hollow intestine" and is chosen because members of this group all have a rather large hollow area in the middle of the body which serves as an intestine. They include more than 9,000 very interesting species; yet most of them are marine and the few fresh-water forms are small so, to the average person, this phylum is hardly known. While in swimming during a vacation at the seashore, perhaps a bather's unfortunate contact with a jellyfish represents the extent of familiarity with this group.

Class—Hydrozoa

As a type animal we will pick **hydra** which is not typical of the phylum in its habitat since it is a fresh-water form, but does serve very well to illustrate the life processes of the phylum. In nearly all sections of the United States hydra can be found attached to submerged rocks and leaves in ponds, lakes, and streams where the water does not become too foul or get too warm. As usually seen, the main part of the body consists of a slender cylinder which is attached temporarily to some solid object at one end, called the **base,** and bears the **mouth,** surrounded by from five to seven **tentacles** at the other end. The mouth is found on a little elevated region between the tentacles called the **hypostome,** a word which means "below the mouth." The whole body, including the tentacles, will probably not be more than a half of an inch long. It is able to move about by sliding slowly on its base or by reaching out and attaching the **oral end** (mouth end) and then pulling the **aboral end** (away from the mouth end or base) up and so on in the same manner as a measuring worm moves. Hydra has also been seen putting the oral end down and flipping the base over and attaching it and so on like an acrobat doing handsprings. If you touch one of the tentacles with a small object, you will probably see the hydra jerk itself up into a little ball less than a fourth the length of the extended form. This is an avoiding reaction used to get away from enemies. When you compare this

variety of bodily activity with the quiescent condition of scypha, it is evident that this animal has something that seems to tie the cells together so that hydra reacts as a unit.   This is a **nervous system.**   It cannot be seen in the living hydra, but by treating it with a stain known to be absorbed by nerve tissue, it is possible to bring out a complete network of nerves running all over the hydra's body, being a little more concentrated at the oral end which is where most of the activity occurs.
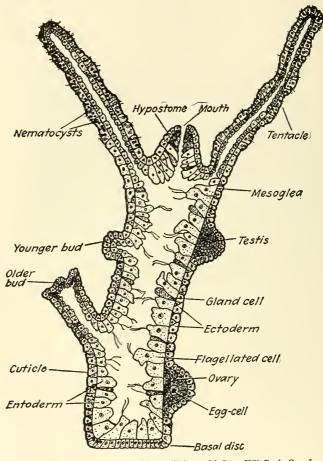

Photo by P. S. Tice

Fig. 9.1.   Living hydra with bud attached.

There seems to be no nerve center which could be compared to a brain of higher animals.

Hydra does not aggressively seek out its food, but, when hungry, extends itself and its tentacles to the maximum length and waits for its food to come to it.   Eventually some small water animal, such as a water flea, will swim within reach and touch one of the tentacles.   Immediately the flea will be showered with dozens of poisonous arrows shot from stinging capsules, called **nematocysts,** which cover the tentacles and are found in smaller numbers on the body.   At the same time the tentacles,

like those of an octopus, will wrap themselves around the unfortunate water flea and the now insensible victim will be carried to the mouth by the tentacles for **ingestion.**

Animal Biology, Wolcott, McGraw-Hill Book Co., Inc.

FIG. 9.2. Diagram of a longitudinal section of hydra bearing a testis, ovary, and two buds.

With respect to **digestion,** hydra is a transitional form. Ingested food passes into the **gastrovascular cavity,** where it is exposed to **extra-cellular enzymes** which flow out of the cells lining this cavity. These enzymes, however, accomplish only a partial digestion. When the food is broken down into small bits, these small particles will be engulfed by the cells which line the cavity in much the same way as

FIG. 9.3. Capture and ingestion of a small water animal, cyclops, by hydra. The animal is first ensnared by the tentacles and stung into insensibility by the nematocysts. Then it is forced into the mouth.

an amoeba engulfs food particles. Within the cells digestion is completed by **intracellular enzymes.** This is an advance over the condition found in the sponges, which had only intracellular digestion, but is still more primitive than more advanced forms of animals which have only extracellular digestion. This partial extracellular digestion does have its advantages, however. It permits the hydra to ingest large pieces of food which can then be broken down into pieces small enough for the cells to engulf. The sponges can utilize only those food particles small enough for the cells to engulf without benefit of this

pretreatment. The mouth is the only opening to the gastrovascular cavity in hydra—hence it must serve the dual function of a mouth and an anus. Indigestible wastes are egested through the same opening that is used for ingestion.

Some hydra are green in color because of the presence of certain one-celled algae within their cells. These algae apparently live here as "guests" and seem neither to harm nor to help their hosts to any appreciable extent. Such associations are sometimes called **commensalism.**

Respiration and **excretion** in hydra are taken care of by simple diffusion as described for the sponges. Practically every cell of the hydra's body is exposed to water, either on the outside of the body or within the gastrovascular cavity; hence diffusion is a simple matter. A cross-section of the body of hydra shows only two layers of cells, the outer one being the **epidermis** and the inner one being the **gastrodermis.** Between these there is a thin layer of a jelly-like substance known as the **mesoglea.**

With respect to **reproduction,** hydra is very much like scypha. It reproduces **asexually** by **budding;** a little bump will appear about one third of the body length up from the base which soon sprouts tentacles and within two or three days is ready to cut itself loose from the parent as a fully developed animal. Buds do not remain attached to the parent and form a colony as they did in the sponge.

In **sexual** reproduction **gonads** are formed; the word gonad refers to an organ that produces gametes. The male gonads, or **testes,** are formed near the oral end and release the sperms through little nipples at the tip of the organs out into the surrounding water. The sperms swim to the egg which is produced in the female gonad, or **ovary,** usually found about a third of the way up from the base, and one of them will unite with it to form the zygote. This zygote drops loose from the parent and develops a hard protective wall around itself and may live through the winter in this condition while the other forms are killed. Sexual reproduction occurs most frequently in the fall, so that these resistant forms may be produced to tide them over the winter. Most hydra still seem to be **hermaphroditic** and can produce both testes and ovaries even though they may not produce both at the same time.

Regeneration in hydra is about the same as it was in scypha. In fact, hydra gets its name from its regenerative powers. According to Greek myth, there was an old sea serpent named Hydra that Hercules went out to slay. The serpent had nine heads and if any one of these was cut off two new ones would grow in its place. Our little animal under consideration was given the same name because its tentacles have

the power to regenerate themselves if cut off. Sometimes a new tentacle will be regenerated when an old one is only injured, and thus a forked tentacle will be formed or two in place of the original one, just as in the myth. This may be seen in the laboratory or may be produced by crushing one side of a tentacle without injuring the other side. Also, you may actually produce a two-headed hydra by cutting the oral end down a short distance; each half of a "head" will regenerate the other half and there will be two complete oral ends attached to a single aboral end. Similar incomplete fissions may occur accidentally in higher animals in the embryonic stage and produce two-headed calves or various degrees of
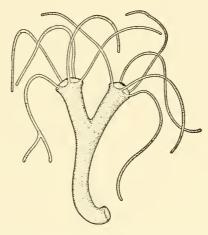
FIG. 9.4. A two-headed hydra produced by cutting the body longitudinally at the oral end and allowing each half head to regenerate the other half. Also, note that one of the tentacles is forked. This was caused by an injury on the side of a tentacle with the subsequent regeneration of a portion of a tentacle from the injured region.

"siamese twins" in human beings. Most of these are unable to live long after birth unless the fission is almost complete, but this is just another example of the similarity of embryos of higher animals with the adults of some of these lower forms.

Obelia is a colonial organism which in many ways resembles hydra, but in other ways is a more complex form of life. When buds form, a new polyp is produced, but it remains attached to the old individual. Soon a large colony of polyps is produced which may appear as a single individual, but it is actually a colony of many animals. Such colonial animals are called hydroids because of their resemblance to the hydra. Each feeding polyp has a mouth surrounded by a circle of tentacles equipped with tiny batteries of stinging cells.

Reproductive polyps are also formed when the colony grows older, and they produce tiny jellyfish called medusae which bud off and swim away. Obelia in the hydroid stage is surrounded by a delicate, transparent shell, which has a series of joints at the base of each polyp. This gives the animal a flexibility so that it can wave to and fro in the water in search of food. Each feeding polyp can withdraw into a cup-shaped cavity in the shell in case of danger. There is a common gastrovascular cavity connecting all the polyps; thus, when one gets a good meal, all the others
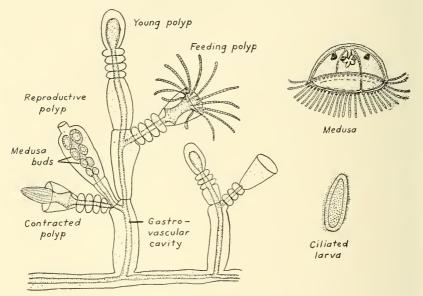
Fig. 9.5. Obelia life cycle.

share it. Since the reproductive polyps have no mouth or tentacles, they are entirely dependent on the food that comes to them through this common digestive and circulatory system.

There are two kinds of medusae—females which produce eggs, and males which produce sperms. After the egg is fertilized, it develops into an embryo which swims around until it finds a suitable place to settle down. Here it becomes attached and develops into a colony of polyps.

Thus we see that obelia has two distinct generations, a hydroid stage which reproduces asexually by budding, and a medusa or jellyfish stage which reproduces sexually. This sort of double life is known as alternation of generations.

Another interesting example of the Hydrozoa is a comparatively large marine form commonly called the **Portuguese man-o-war,** with the scientific name of *Physalia*. Its common name is derived from the fact that it has an air-filled membrane which acts as a float that stays on top of the

FIG. 9.6.   Physalia, the Portuguese man-o-war.   The float is filled with air and stays on the surface, while the long tentacles, armed with powerful stinging cells, trail out in the water beneath.   This one has stung a fish into insensibility and has pulled it up close to the feeding polyps where it is being digested and absorbed.
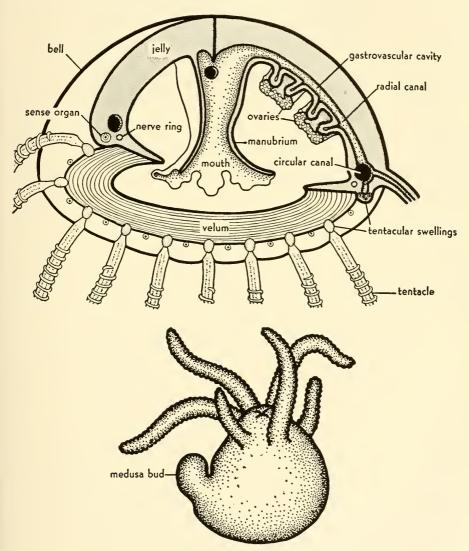
water and resembles the sails of the old men-o-war.   Also, no fighting ship in history, in comparison to its size, was more heavily armed than the Portuguese man-o-war with its thousands of powerful nematocysts which are able to inflict an extremely painful and sometimes dangerous sting on persons that happen to contact the tentacles in the water.   This is a colonial form in which the individuals adhere together after budding and assume different tasks in the group.   Just under the float are quite a number of feeding polyps that are concerned primarily with digesting and absorbing food for the colony.   Some are specialized to take care of sexual reproduction, while others trail out in the water and bear the nematocysts, capture other animals for food, and defend the colony against any possible enemies.   Here we see that the division of labor among polyps, which we first studied in obelia, has been carried to the extreme. This is known as polymorphism, a word meaning "many forms," and can be compared to modern society where each man learns a different trade and only a few actually raise food to eat.   Portuguese men-o-war are often left on the beach after the tide goes out, and bathers may step on them to make them pop like a paper bag full of air.   Bathers must always wear shoes, however, to avoid retaliation by the stinging cells.

An average sized Portuguese man-o-war will have a float about six inches long with tentacles trailing down for several feet.   The float glistens with beautiful iridescent shades of pink, blue, and purple, making a beautiful sight which belies the deadly nature of the tentacles hidden beneath.   This animal does not actively swim, but is carried by the tides and the wind blowing its float which actually does act as a sail.   A fish, unfortunate enough to contact the deadly tentacles, is enclosed and stung into insensibility; then the tentacles contract and draw the fish up under the float where the feeding polyps can go to work on it.   These reach down and spread their lips over its body and secrete their digestive fluid on it and suck up the digesting bits of food as they break off.

One of the most interesting relationships between two animals in the whole animal kingdom occurs between the Portuguese man-o-war and a small fish, Nomeus.   Whereas to venture within reach of the deadly tentacles usually means sudden death to most animals, Nomeus not only ventures within reach, but actually swims in and out among the tentacles in perfect safety and is protected from his enemies that do not enjoy this privilege.   However, the relationship is not a one-sided affair; the little fish will sometimes swim out and offer himself as a temptation to larger fish and, when the larger fish give chase, Nomeus will dart through the tentacles.   Then, as the victim attempts to follow, he finds himself ensnarled and soon he is serving as a square meal for the Portuguese man-o-war and its friend, Nomeus, who swims around and picks up the pieces

that come off as digestion causes the fish's body to begin to disintegrate.

While such a relationship may seem marvelous, especially to those with a limited knowledge of the animal kingdom, it is only one of many such cases which could be mentioned. The word **symbiosis** is used to describe this condition where two organisms live together in a mutually

Animals Without Backbones, Buchsbaum, The University of Chicago Press

FIG. 9.7. Gonionemus, medusa on the top with part of the bell removed to show internal structures; polyp on the bottom.

helpful relationship, each contributing to and each benefiting from the association. Other examples will be mentioned as we go on in our study.

Some of the smaller jellyfish are also in the order Hydrozoa. A jellyfish gets its name from the fact that the mesoglea is highly developed and, if the epidermis is broken, this jelly-like material will ooze out. *Gonionemus* is a good example of one of the smaller ones. It is somewhat umbrella-shaped with long tentacles, bearing the nematocysts, hanging down from the outer rim while the mouth is at the lower end of the handle of the umbrella so that it might be compared roughly to a hydra that has been turned upside down and given a hard slap on its base so as to spread it out to form the umbrella shape. This spread-out portion which curves downward at its outer edge is called the bell. The animal swims by rhythmic pulsations of the bell. The water is slowly sucked up into its undersurface, like air swelling out a parachute, and then is suddenly expelled as the bell contracts, thus propelling the animal in the opposite direction. This is the original jet propulsion which the jellyfish have been using for thousands of years before man thought of its use in connection with aircraft. A jellyfish swimming through the water exhibits one of the most beautiful illustrations of poetry of movement as the tentacles wave back and forth in unison with the pulsations of the bell.

Like obelia, gonionemus has alternation of generations, but the polyp stage is quite small in comparison with the medusa stage. The polyp of gonionemus looks very much like hydra and the medusa bud off at the side in this asexual phase of reproduction.

There are other small jellyfish that live in fresh water, and some inland lakes may be filled with them at certain seasons of the year. At other seasons they seem to have disappeared entirely, but a careful search will reveal them in the less conspicuous polyp stage.

Class—Scyphozoa

Members of the class Scyphozoa are large marine jellyfish which may reach a diameter as large as two feet. They closely resemble the hydrozoan jellyfish in its medusa stage and have a very inconspicuous or no polyp stage whatsoever. The gonads and other internal organs can be seen forming a beautiful geometrical pattern through the transparent outer covering and as they float on the surface of the water they look more like a beautiful piece of lace than anything that could do a person any bodily harm. Many a newcomer to the seashore has picked up these beautiful creatures, while in bathing, to examine them more closely, only to drop them quickly as the powerful nematocysts come in contact with

Photo by W. K. Fisher

FIG. 9.8. Jellyfish. Pelagia that have been left on the beach by the receding tide.

the skin. Not all of the large jellyfish sting man—the white jellyfish (*Aurelia*) can be handled without ill effects, but you must be careful of the red jellyfish.

Class—Anthozoa

The word Anthozoa means flower animals and, when genera of this class are seen grouped together in warm tropical waters, this name certainly seems appropriate. The beautiful display of color harmony and body form rivals the most gorgeous flower garden that has ever been grown on land. One member of this class, the **sea anemone,** is named after a flower, the anemone; but, seen in its natural habitat, it seems to resemble more closely a chrysanthemum, a marigold, or a dahlia in its different forms and colors. This animal is the polyp type in shape, like hydra, but it is much larger than the other polyps we have studied and has more tentacles which come out around the mouth and appear like the petals of a flower. While, as we have indicated, they are very abundant in tropical waters, they are by no means restricted to these areas. They are common, for instance, along our north Atlantic coast where they attach themselves to piers and other solid objects near the shore. The genus usually studied in the laboratory, *Metridium,* is such a form and, after a glance at this dull brownish animal, the student may decide that all of the descriptions of the beautifully colored sea anemones were exaggerations, to say the least. However, it is a general rule that animals living in tropical waters are brilliantly colored, whereas those living in more temperate and frigid waters are dull in their coloration; and the sea anemone is a good illustration of this point. The dull coloration is a

positive protection in the dull surroundings found in temperate waters since it tends to blend the animal with the background and to make it less easily seen and consequently less easily caught by some larger form. On the other hand, such a dull colored animal placed among the brilliant rock, coral, and seaweeds of the tropics would stand out like a black sheep, so we find that the tropical forms have taken on brilliant hues which cause them to be better adapted to their surroundings.

There is another small polyp form in this class, not much larger than hydra, yet it is an architect that has constructed some of the largest structures that have been produced by any animals since time began,
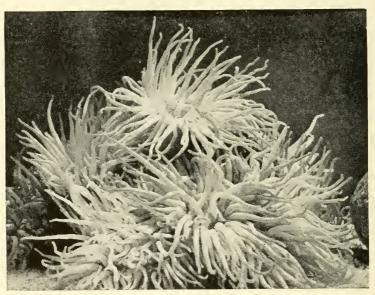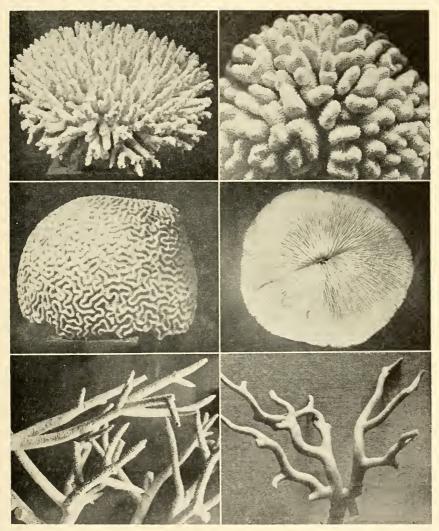
Photo by Winchester

FIG. 9.9.   A group of sea anemones with their spreading tentacles is a beautiful sight, resembling an underwater flower garden.

including man. This is the little coral polyp, not much more than a half an inch long yet building islands and reefs of tremendous size, beside which the pyramids of Egypt are insignificant by comparison. The great barrier reef which runs along the eastern shores of Australia is more than 1,200 miles long, yet it was built entirely by the patient efforts of these little animals. They naturally have soft bodies and secrete little protective cups of limestone around themselves and, as they bud and grow and secrete more limestone, they gradually build up a sizeable structure. Growth of a mass of coral may be no more than a half an inch a year; yet, in the eons of time in which they have been growing, the huge

masses mentioned have been produced. The South Pacific waters are dotted with many thousands of coral islands, and the coral reefs that lie just under the surface of the water are a great hazard to ships traveling

Photos by Winchester

FIG. 9.10. Varieties of coral. The coral polyps are quite varied in their methods of depositing their limestone coverings, giving many interesting and beautiful forms of coral deposits. From left to right and top to bottom these are: Star coral, Pacillopora grandis; finger-like madrepore, Madrepore digitata; Brain coral, Meandrina sinuosa; mushroom coral, Fungia dentata; staghorn coral, Madrepore cervicornis; and precious red coral, Corallium rubrum.

uncharted areas in this region. The Florida keys are examples of such islands in our own country. These are surrounded by coral reefs upon which many ships have been wrecked, especially during our early history when small vessels had to go around the southern tip of Florida to reach the cities on the Gulf of Mexico.

In spite of the great abundance of coral of many varieties, there is one that is referred to as precious coral which may be valued as high as $600 an ounce. This is found primarily in the southern Mediterranean waters and off the coast of Japan. It is usually a pink or red color and makes beautiful bracelets, necklaces, and similar ornaments. It usually grows in water from 90 to 900 feet deep and is a more beautiful sight in its living condition, with the delicate tentacles waving forth from the brilliant skeleton, than it is when it has been made into a necklace.

Classification and Derivation of Scientific Words

Phylum.   Coelenterata (Gr. *koilos,* hollow; *enteron,* intestine; refers to the fact that the body of these animals is somewhat like a hollow intestine).

Class A.   Hydrozoa (Gr. *hydra,* water serpent described below; *zoon,* animal; these are hydra-like animals).

Genus 1.   Hydra (Greek myth, Hercules slew a water serpent called Hydra which had nine heads and if one were cut off two would grow back in its place; refers to the regeneration of tentacles in this genus).

Genus 2.   Physalia, Portuguese man-o-war (Gr. *physallis,* a bladder; referring to the bladder-like nature of the float).

Genus 3.   Gonionemus (Gr. *gonia,* angle; *nema,* thread; possibly refers to the thread-like tentacles hanging down at an angle from the edge of the umbrella).

Class B.   Scyphozoa (Gr. *skyphos,* cup; *zoon,* animal; refers to shape). The large jellyfish.

Class C.   Anthozoa (Gr. *anthos,* flower; *zoon,* animal; refers to the flower-like appearance of these animals).

Genus 1.   Metridium, a sea anemone (L. *metricus,* rhythm; refers to the symmetrical arrangement of tentacles and other body parts).   (Common name from the flower anemone which these resemble).

Genus 2.   Astrangia, a coral (Gr. *aster,* star; *angeion,* a little vessel or receptacle; refers to the star-shaped little receptacles which coral polyps secrete and in which they live).

REVIEW QUESTIONS

1. How is the presence of a nervous system evident in hydra as contrasted with scypha?

2. What advantage does hydra's method of digestion have over that of scypha?

3. Describe reproduction in hydra.

4. If you found a hydra in the laboratory with a forked tentacle what explanation for its presence could you offer?

5. What is meant by an animal colony?

6. How does the Portuguese man-o-war obtain its food?

7. What is meant by the term symbiosis? Can you think of other examples than that mentioned in this chapter?

8. Explain locomotion of the jellyfish.

9. Illustrate alternation of generations by a discussion of the life cycle of obelia.

10. Why are animals that live in tropical waters generally more brilliantly colored than those that live in temperate waters?

11. How does the life cycle of gonionemus differ from that of obelia?

12. Tell how coral reefs are constructed.

10

The Flatworms—Platyhelminthes

When the average person hears the word "worm" he may think of fish bait or slimy, crawling creatures that are quite repulsive to many people, those of the feminine sex particularly, and he may use the word to express his contempt for some spineless, repulsive person by calling him a worm. To the zoologists, however, the word has a much broader meaning; three of the great phyla of the animal kingdom are given over to worms and they are known to be extremely abundant with hundreds of important species and of very great economic importance.

This first phylum of worms is called the flatworms because the body is flattened in contrast to the next phylum of worms which has a rounded body.

Symmetry of Flat Worms

An examination of the worms of this group reveals that their bodies consist of two sides, right and left, each of which is practically a duplication of the other except that the placement of parts is exactly reversed. We might say that one half is like a mirror image of the other half. Such an animal can be cut in only one body plane to give two halves approximately alike, since the two ends of such animals are different also. We call such an arrangement **bilateral symmetry** and we will find this body plan in nearly all the animals yet to be studied.

Animals with this type of symmetry have six body directions or surfaces. If you think of a dog as a typical bilaterally symmetrical animal we can easily describe these. The head end, or front, of the dog is **anterior,** while the tail end, or rear, is **posterior;** the back, or the surface which is up, is **dorsal,** while the abdomen, or the surface which is down, is **ventral;** and, finally, the sides are **right lateral** and **left lateral.** In order for these directions to apply to man he would have to get down on his hands and knees, but the plan of symmetry is the same. Whenever we have only one structure, such as a nose, it is placed in the median plane of the body; if we have two, such as eyes, they are placed in the same spots on opposite sides of the body. There is some force at work which correlates the two sides of the body and they will be balanced.

Most people use their right arm more than twice as much as their left; yet, by actual measure, there will be little difference between them because of this balancing action. Otherwise, we would tend to develop in a lop-sided manner so that we could not easily stand upright, not to mention the disuption of symmetry of lines that makes a well-developed body a pleasing sight aesthetically. Sometimes this action goes to undesirable extremes; one eye may be blinded and the other goes blind in "sympathy" with the first; and dentists frequently find that a decayed tooth on one side of the head is duplicated by a similar decay on the opposite side.

The metazoan animals previously studied have symmetry also, but of a different nature. They have **radial symmetry** in which the body parts radiate out from a central point, such as the spokes of a wheel. Such an animal can be cut in any longitudinal plane to give two halves approximately alike. The cut must be longitudinal, because the two ends differ and a transverse cut would yield two different halves. A layer cake with icing on the top and none on the bottom would be radially symmetrical and you could cut it in many ways to give two halves alike as long as the cut went through the center and was in the vertical plane. Hydra and jellyfish are good examples of radial symmetry, and such animals have only two directions in comparison with the six mentioned for the bilateral animals. These two are usually referred to as the **oral** and **aboral** surfaces which are the mouth surface and the surface opposite the mouth, respectively.

Free-living Flatworms—The Turbellaria

This class includes the free-living flatworms which make up a comparatively small number of the species found in this phylum. We speak of these as being free-living in contrast to the others which are parasites in the bodies of other animals; but, since parasitic forms tend to become highly modified for their specialized existence, it is better to choose one of this class as a type animal for the phylum. The little fresh-water flatworm, *Planaria,* is a very good example.

Planaria leads an existence that will probably seem rather dull to most of you; he spends his life crawling around under rocks and leaves which lie at the bottom of ponds and streams. He has a body about a half an inch long with a distinct head on one end which bears a pair of **eyes,** but he seems to be cross-eyed because of pigment spots in the inner side of both eyes. The planaria is not able to see definite images with these eyes since there is no lens to focus an image, but they are light sensitive. You might say that he can see about as well as you can with

your eyes closed. You can still detect changes in light intensity with your eyes closed and, therefore, become aware of movements which cause variations in this intensity. Down under the rocks at the bottom of a stream there is not much light to see by anyway, so this lack of visual acuity is of no great consequence in the life of planaria.

If you watch one of the animals moving it will appear to be gliding along over a surface without any noticeable effort, such as the body con-
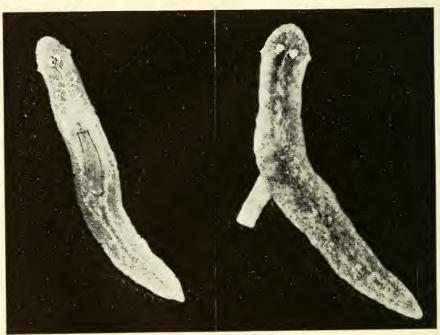

Photo by Winchester

FIG. 10.1. Planaria, a free-living flatworm. The individual on the left has the proboscis retracted and it can be seen faintly near the center of the body. The individual on the right has extended the proboscis. Some of the branches of the intestine show near the anterior end of the animal on the left.

tractions that characterize the crawling of a snake. This is possible because the body is covered by microscopic **cilia** which beat to propel the animal forward in a thin layer of mucus which is secreted by the body as it moves along. You will also notice other movements from time to time as the body shape changes and the head is turned from side to side as if it were feeling its way as it goes. Such movements are made by the three types of muscles which are found in planaria. These consist of **longitudinal muscle fibers,** which can contract to shorten the body and make it fatter; **circular muscle fibers,** which can contract to constrict the

body to make it thinner and longer; and **oblique muscle fibers,** which can contract to shorten the body obliquely and thus turn it to the side. Thus, planaria is the first type animal to have a muscular system; and, since we learned in the last chapter that the muscles are formed from mesoderm, this also indicates that planaria has a **mesoderm,** or middle layer of cells, in addition to the ectoderm and endoderm. With three body layers, planaria is a **triploblastic** animal.

If you put a little piece of liver or other fresh meat in shallow water at the edge of a pond in which there are planaria, you are likely to find it covered with a mass of these animals within a few hours. If you remove them to a dish of clear water you will be able to observe **digestion** and **ingestion.** Since the piece of liver is too large for ingestion as it is, the planaria throws out the **proboscis** from its mouth, which is located
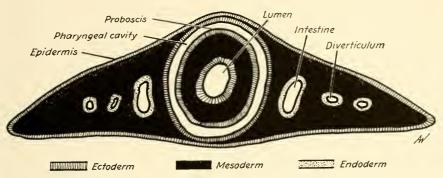
Fig. 10.2. Cross-section of planaria through region of proboscis showing the body parts formed by the three germ layers.

about a third of the body length from the posterior end on the ventral surface, and attaches it to the meat. The proboscis is somewhat similar to the trunk of an elephant in structure and function except that it is normally kept retracted inside the mouth. Digestive juice is poured onto the meat through the proboscis, and the bits of partially digested food are sucked up as they break off. These food particles then enter the **intestine** which has three major branches, one anterior and two posterior, with many smaller branches called **diverticula.** These branches carry the food to all parts of the body where the cells engulf the still incompletely digested food particles and complete digestion inside the cells, thus combining **extracellular** and **intracellular digestion** as was done in hydra. Small animals and smaller bits of food will be taken directly into the intestine through the proboscis without this preliminary digestion outside the body, but the planaria will usually take time to secrete mucus on the food to insure its smooth passage into the intestine.

When the time comes for **egestion,** planaria is faced with the same problem that hydra had; there is only one opening to the digestive tract, so the mouth must serve as an anus also and the indigestible food residue is expelled through the mouth.
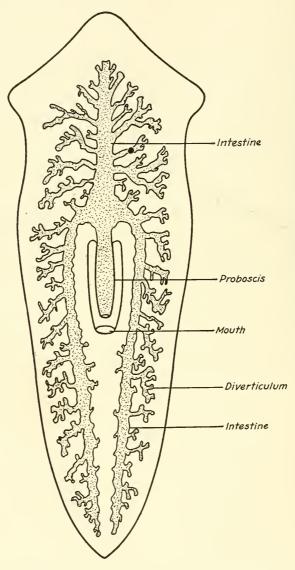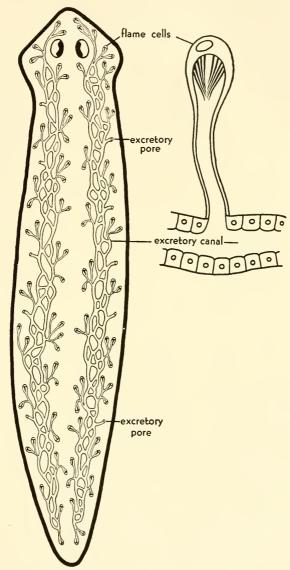

FIG. 10.3.   Digestive system of planaria.   The highly branched condition of the system is shown in this drawing copied from a photograph of a planaria that had been fed a dye that filled the intestine and its branches.

Respiration is still not represented by any system, and there is direct absorption of oxygen from the water by individual cells and the giving off of carbon dioxide in the same way.

flame cells

excretory pore

excretory canal

excretory pore

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Fig. 10.4. Excretory system of planaria. Note the extensive distribution of the flame cells that pick up the wastes.

For **excretion,** however, we find a system has been developed.   Scattered over the body there are many **flame cells** that pick up the waste products of metabolism as they are thrown off by the individual cells. A flame cell is shaped like a funnel with cilia around the mouth; these beat so as to suck the excretory products down into the funnel, somewhat
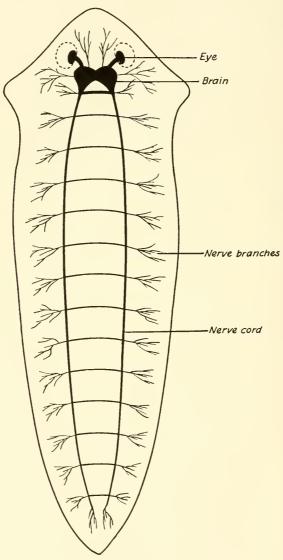
Fɪɢ. 10.5.   The nervous system of planaria.   Note the ladder-like appearance of the
       two nerve cords with the connecting nerves between them.

like the cilia, lining the oral groove of paramecium, sucked food down into the mouth. When seen under the microscope these beating cilia resemble the flickering of a flame—hence the name flame cells. After being sucked into these cells, the waste passes into one of two **excretory tubes** located on either side of the body. These, in turn, empty it into the surrounding water through **excretory pores** which are very small holes opening on the dorsal surface with the first pair lying directly posterior to the eyes and several other pairs farther down the body.

The extensive branching of the digestive and excretory system is necessary in the planaria in order to carry the food to all parts of the body and to bring back the excretory wastes from all regions, since there is no circulatory system to take care of transportation of materials from one part of the body to another. More advanced animals with blood coursing all over their bodies have the digestive and excretory systems localized and depend on the blood to distribute the food to the more distant parts of the bodies and to bring back the wastes of metabolism to the excretory organs for removal and elimination.

In hydra we found our first nervous system consisting of a network of nerves without any brain, but with a concentration of nerves at the oral end. In planaria this concentration of nerve tissue forms a **brain** in the anterior end, which exercises a degree of control over the entire body, thus giving a better coordination than was possible in hydra. The brain has two distinct lobes with a **nerve cord** from each running the length of the body on either side. Large nerves run across to connect these two nerve cords at regular intervals and give a structure resembling a ladder, which is frequently called a **ladder-like nervous system.** Many smaller nerves branch off from these and run to all parts of the body to pick up sensations resulting from various stimuli and to transfer impulses to the muscles for the proper reaction to these stimuli.

For instance, if we stimulate the sense organs of sight, the eyes, with a strong light, the muscles respond and take the animal in the opposite direction; if we stimulate the sense organs of touch by sticking a part of the body with a needle, the muscles will move it away in the opposite direction; if we stimulate the sense organs of taste by placing some food in the water, the muscles will bring it to the food.

Thus we see that some of the nerves are **sensory** and pick up sensations from sense organs to carry them to the main nerve cords and brain, while others are **motor** and carry impulses from the brain and main nerves to the muscles in order to produce the proper response to the stimulation.

When we come to study reproduction, we find that planaria has a very well-developed **reproductive system** with many of the organs similar in

structure and function to those of man. They are still **hermaphroditic,**
so we find a complete set of both male and female organs in each animal.
Fig. 10.6 shows these organs and their relationships to each other. Since
planaria is bilateral, each set of organs is duplicated on either side with
the exception of those in the center, but in the diagram only one sex is
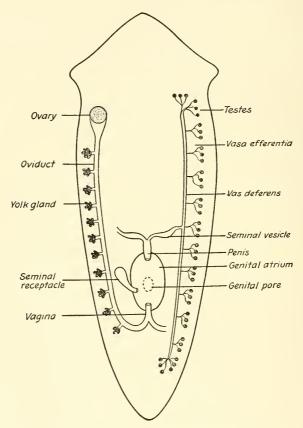shown on each side to avoid confusion that would exist if the organs

Fig. 10.6. The reproductive system of planaria. Male organs are shown on the right
and female organs on the left to prevent confusion of the two. Both sets of organs are
the same on either side.

were shown overlapping one another. All the organs necessary for
sexual reproduction are present in each animal, yet there is sexual union
between two animals in which sperms are exchanged. This act is called
copulation, which is a term used to describe the union between two ani-
mals in which sperms are transferred from one to the other and applies
to all forms of animal life.

In planaria, during copulation, there seems to be a mutual exchange of sperms with both animals serving a male and female at the same time. Sperms are produced in the numerous **testes** and make their way through the slender **vasa efferentia** (sing. vas efferens) into one of the two **vasa deferentia** (sing. vas deferens) and thence down into the **seminal vesicles** which act as a storage chamber for the sperms until the time comes for their discharge. In copulation, the **penis** of each animal is thrust through the **genital pore** of its partner and the seminal vesicles contract to force the sperms into the **seminal receptacle** of the other. Then the animals separate and a short time later eggs are produced by the **ovaries** and make their way down the **oviducts** where they meet the sperms which come out of the seminal receptacles and journey up the oviduct to unite with them to form zygotes. As the zygotes continue down the oviducts the **yolk glands** secrete many yolk cells to nourish the embryos. When these reach the **genital atrium** a group of from four to twenty zygotes and thousands of yolk cells will be surrounded by a cocoon which then passes out of the genital pore and is usually attached to the under side of a rock or a leaf or similar underwater structure. The embryonic planaria develop within the cocoon, deriving nourishment from the yolk cells for several weeks, and then break this confining wall and crawl out to start life on their own.

It may seem strange that, with complete reproductive organs of both sexes in its body, planaria should copulate with another individual and thus fertilize its eggs with sperms from another animal. However, similar cases are found in many forms of life. Most flowering plants have both male and female organs in each flower, yet elaborate mechanisms have been developed which result in cross-pollination rather than self-pollination. Insects and the wind may be used to spread the pollen from one flower to another. We have already learned how paramecium undergoes a complicated reaction known as conjugation and the only apparent biological value of such a union seems to be the exchange of hereditary material contained in the nucleus. A process which is so widespread in nature must have some biological value— some value in survival which causes the process to become established in so many cases.

For one thing, the production of variety among the offspring which results from the blending of genes from different parents is of major importance. The process of natural selection cannot operate unless there are inherited differences among living things. Also, there is often an immediate advantage to the offspring. In general, the offspring which come from two different parents are more vigorous than those which result from self-fertilization. In higher forms of animals there

can be no self-fertilization because there are separate sexes, but something akin to it is found when there is a breeding of closely related individuals. A wise cattle breeder may have a perfectly good bull on his ranch, yet he may go to great lengths to breed some of his cows to other bulls because they may be sisters, daughters, or other close relatives of the bull he owns. He has learned that this outbreeding tends to produce more vigorous offspring than inbreeding. Self-fertilization and inbreeding tend to bring out any latent harmful characteristics which may be present, whereas outbreeding tends to cover up these and allow the more beneficial characteristics to be expressed.

The same principle, of course, applies to human beings, and society has long recognized this fact. Many states have laws against cousin marriages, and incestuous relationships are considered among the worst of all human sins. This does not imply that all children of cousin marriages or other relatives will be defective, but only that weak family traits, which might be covered up in a nonrelated marriage, will tend to prevail in the children when both partners carry these same family weaknesses even though they themselves might not show them. It is quite probable that the vigor of the American nation as a whole can be traced to this same principle. We are somewhat of a melting pot where members of many races have intermarried, and by this principle we tend to manifest the best qualities of them all. This is sometimes referred to as **hybrid vigor** and is evident in practically all forms of plant and animal life where the relationships between parents are distant.

Sexual reproduction seems to be the dominant method in planaria, but it still holds on to an asexual method also. This is by a transverse **fission** which has a very interesting physiological explanation. As mentioned under the discussion of the nervous system, the brain, which is at the anterior end of the body, acts as a center of control and coordination of all parts of the body. As the animal grows longer, however, under favorable living conditions, it seems that the posterior end of the body gets so far away from the brain that the brain gradually loses its control over it and it begins to act somewhat independently. A new center of coordination develops at the posterior end and the planaria literally pulls itself in two as a "tug of war" develops between the two ends. The lost portions of each half are then regenerated. This method of reproduction can be prevented if the planaria are kept in containers greased with petroleum jelly. On such a slick surface, there can be no "tug of war" and the two ends are not pulled apart.

Although planaria shows considerable specialization of tissues, it still has a very great power of regeneration and is an excellent animal to experiment with in this connection. If you slit the head down the middle

with a sharp razor blade, each half will regenerate the missing half and the result is a two-headed animal. These two can then be split to give four, and an eight-headed planaria has been produced by a splitting of the four. Grafting is also possible just as it is in plants; a part of one animal can be cut off and placed in an incision of another animal and it will grow there.

The regenerative power of the planaria also enables it to survive long periods without food. If you are the type that forgets to feed the cat or the canary, you should keep planarians for pets. They can live for nine months without food. During this time they derive nourishment from their own body, starting with their reproductive organs and then other parts as needed. They may shrink from a half an inch to about one

Fig. 10.7. Regeneration of planaria. The posterior end of this animal was slit longitudinally. Regeneration produced this condition.
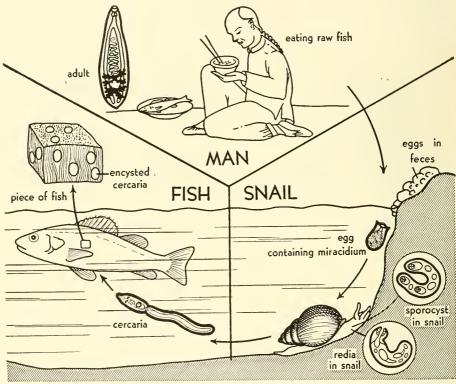
seventh of an inch during this long fast, but when food again becomes available they quickly restore the tissues which have been absorbed for nourishment and are no worse for the experience. To a certain extent, all animals utilize their own body tissues for nourishment during times of starvation. A glance at pictures of starving human beings shows the emaciation that develops as food is drawn from the various parts of the body. Of course, entire organs are not lost as in planaria, for man could not regenerate them if they were. However, a starving person may lose as much as one half of his body weight due to this process and still be restored to a normal state when he can again eat properly.

Flukes—The Trematoda

Members of the class Trematoda are commonly called flukes. They have a body structure somewhat like planaria, but they are all parasitic rather than free-living forms. They parasitize many parts of the bodies of higher animals—there are blood flukes, lung flukes, liver flukes, intestinal flukes, and even some that cling to the external surface

of some water animals. The life cycles of flukes often include one or more hosts in addition to the one which is infested during the adult stage. Quite often the snail is one of the alternate hosts which serves to harbor the larval stages of these parasites.

A good example of this class is the Chinese liver fluke, *Chlonorchis* (*Opisthorchis*) *sinensis,* which is found in large numbers of people in China, Japan, and Korea because of their living and eating habits. These

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Fig. 10.8. Diagram illustrating the life cycle of the Chinese liver fluke.

adult flukes live in the liver and sometimes cause a partial breakdown of that organ called liver rot. Also, a type of jaundice may result from the clogging of the passageways for the bile. The animals are hermaphroditic like the planaria and, after fertilization, the eggs are released and make their way down the bile duct, into the intestine, and eventually out of the body along with the indigestible food or **feces.** The eggs must reach water in a short time in order to continue the cycle. This

they frequently do because many of the houses are built over or near the water and the rivers and lakes offer a convenient means of disposal of sewage. If snails of the right species eat these eggs, they hatch into tiny larvae (miracidia) which go through a series of asexual reproductive phases within the snail's body (sporocysts and redia). Eventually, a large number of larvae (cercariae) possessing tails for swimming are produced by this method. These break out of the snail and swim around in the water aimlessly until they come in contact with a fish; they then burrow through the skin of the fish and encyst in its muscles (encysted cercariae). Many of the people in these oriental countries practically never cook fish. It may be sliced and placed on top of steaming rice to warm it up a little or perhaps dipped in a hot sauce that tends to disguise the "fishy" raw taste, but the encysted larval flukes are not destroyed by such treatment. When they reach the stomach the cyst wall is digested off and, as they pass into the small intestine, the little wiggling larvae find the bile duct and swim up it to the liver. Here they grow into adulthood along with their relatives that have survived this precarious journey from one person to another. In some regions of the orient this fluke infects more than 75 per cent of the inhabitants.
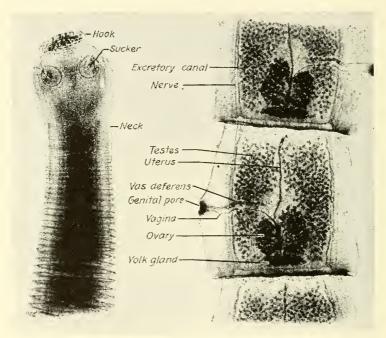
The human liver fluke is not able to spread in the United States. There is a sheep liver fluke (*Fasciola hepatica*), however, that is rather abundant and often causes serious losses of sheep. The snail also acts as an intermediate host for this parasite, but the larvae (cercariae) from the snail do not go to fish for encystment. Rather they crawl up a blade of grass or other succulent plant which grows up out of the water. Here they may be eaten by sheep and the cycle is completed.

The flukes represent another case of alternation of generations such as was first studied in obelia in the coelenterates. There is a sexual generation alternating with asexual generations.

Tapeworms—The Cestoda

This class includes the tapeworms that are so very abundant in practically all mammals and many of the other vertebrates. Their bodies are more specialized than the flukes, and they have very little similarity to planaria externally. The body of an adult tapeworm consists of a head, or **scolex,** which is attached to the intestinal wall of its host with the aid of suckers and sometimes hooks, and a series of many segments, or **proglottids,** which come off from the neck of the scolex and trail out into the intestine, usually for several feet. It somewhat resembles a tape measure, from which it derived its name. Because tapeworms are

bathed with digested food they have found it unnecessary to have a digestive system, and not even a vestige of this system remains. Their muscular system is poorly developed and they usually just lie passively in the intestine soaking up the food needed for their growth and metabolism. When it comes to reproduction, however, we find that tremendous emphasis has been placed on this system. Reproduction seems to be the most important thing in a tapeworm's life judging by the development

Courtesy General Biological Supply House

FIG. 10.9. Scolex and proglottids of the common dog tapeworm, *Taenia pisiformis*. On the left, the scolex and the immature proglottids. Note the hooks and suckers on the scolex, which are used to attach the tapeworm to the intestinal wall. On the right, mature proglottids. Most of the structures which are visible are organs of reproduction. It can be seen that each proglottid is almost a complete individual in itself.

of these organs. A complete set of male and female organs is found in each proglottid, and it has been suggested that each proglottid is a separate animal that is produced by a process somewhat like budding at the neck. There is good reason to think of them in this way, although they do have nerve cords and excretory canals that run the entire length of the worm, which tie the individual proglottids together into some sort of unified whole.

There is a reason for this emphasis on reproduction; the life cycle is very precarious and the chances of any one egg completing it and getting into another primary host are quite small. They make up for this by giving over their bodies in a large measure to the production of eggs, and the necessary sperms. Thus, enough of them will complete the cycle to keep the species going. A beef tapeworm, for instance, may live in your body for ten years and produce more than 250 million eggs each year during this time. If we assume that the number of beef tapeworms is not increasing or decreasing, that would mean that any one egg has one chance in 2,500 million to carry out its destiny to proper conclusion. Nature achieves her ends by devious and remarkable methods.

A good example of this class is the pork tapeworm, *Taenia solium,* which is very common in sections of Europe and other parts of the world and at one time was very prevalent in the United States, but our efficient system of meat inspection has made it comparatively rare today.

As an adult this tapeworm is found in the small intestine of man and normally reaches a length of from six to ten feet with a width of about two fifths of an inch at the widest portion which is at the posterior end. This may seem like a great length for man to accommodate, but the human small intestine is about 24 feet long so there is plenty of room for several of these tapeworms without crowding. They do some harm by absorbing food intended for human nourishment, but the main damage seems to be due to an absorption of their waste products which may cause anemia, nervous disorders, and other troubles. Also, on some occasions they may congregate in one portion of the intestine to such an extent as to cause obstruction which interferes with the normal passage of materials through the intestine.

Although they continue to produce new proglottids from the neck of the scolex throughout their life, they do not increase in length after they have reached maturity, because proglottids break off at the posterior end about as fast as they are produced at the anterior end. When a proglottid is first produced at the neck it is small; as it is pushed away from the neck by new proglottids being formed it grows in size and develops its sexual organs. The male organs seem to mature first and release the sperms into the intestine so that they can swim down and fertilize mature eggs in other segments. Then the eggs mature and are fertilized by incoming sperms and shortly begin their embryonic development within the uterus. As more eggs are produced the uterus swells until it fills the proglottid and it is bulging with young embryos. By this time the proglottid has reached the posterior end of the tapeworm and is said to be ripe. Then, together with several other segments, it breaks loose and is carried from the body in the feces.

In order for the cycle to continue, a hog must eat these ripe proglottids, and this frequently happens. Once in the intestine of the hog, the shell of each egg is digested off and the little **embryos,** which now have six hooks on their bodies, escape. They immediately burrow their way into the intestinal wall and get into the blood stream through the little capillaries which are so abundant in this region. They are then carried over the body by the blood and leave the blood vessels when they reach some of the muscles, which they bore into and encyst. Here they form what is called a **bladder worm** which for many years was thought to be an entirely separate animal. They are large enough to be seen with the naked eye and are composed of an inverted scolex inside of a rounded bladder. In this stage they live in a dormant condition throughout the life of the hog.
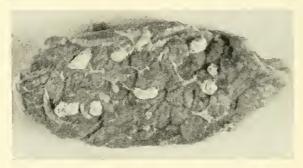
Photo by Winchester

Fig. 10.10. Bladder worms of the pork tapeworm in a piece of infected pork. There are eight worms visible in this piece of pork detected by meat inspectors at a slaughter house.

Because they are rather easily spotted by trained meat inspectors, it is very unusual for pork sold on the market to carry them. Thorough cooking, of course, will kill them so there will be no infection, even though they are present in the meat. However, it must be remembered that, if fried very rapidly, a piece of pork sausage may be thoroughly browned on the outside, yet the inside may be hardly warmed. It has been shown that it takes a temperature of about 132 degrees to kill the bladderworms. This does not seem very high when we consider that we have air temperatures of 120 degrees and higher in some sections of our country during the summer, yet a large piece of meat such as a ham, after being boiled for two hours, may show a temperature of only 123 degrees in its center.

The beef tapeworm, *Taenia saginata,* has exactly the same life cycle except that cattle are the intermediate host. These worms are extremely

rare in the United States, but in some sections of the world, such as Tibet, nearly all the people have them due to their habit of broiling large chunks of beef over open fires, which thoroughly sears the outside, but does not penetrate to the center.

The longest tapeworm of man is the fish tapeworm, *Dibothriocephalus latus,* that has been measured to a length of 60 feet, with a width of about an inch. There may be as many as 4,000 proglottids in such a worm. The cycle is similar to the ones just studied, with the fish substituting for the hog or cow; however, in this case, another animal is also involved in the life cycle. This is a small fresh-water crustacean about a sixteenth of an inch long that eats the tapeworm embryos and then, in turn, is eaten

Photo by Winchester

FIG. 10.11. Dwarf tapeworms *Echinococcus granulosus,* of the dog. These tapeworms are only about a quarter of an inch long and do little harm to the dog, but if the eggs are eaten by man they cause a huge cyst to develop in the muscles.

by a fish. Thus, the embryos can find their way into the fish's muscle, later to be devoured by man in the raw or poorly cooked condition. This parasite is found rather abundantly in regions of the Great Lakes which often serve as a means of sewage disposal and also as a source of fresh fish. Many of the people who live near the lakes, especially those of Scandinavian ancestry, like to eat smoked fish, and smoking apparently does not always kill the larvae in the fish. Because there are so many popular vacation spots in these regions, vacationists may become infected, taking the tapeworms home with them, and thus the infection seems to be spreading in the United States.

Man, himself, may sometimes harbor the bladderworm through the ingestion of the eggs of tapeworms that live in other animals. One of these

is from the dwarf tapeworm of dogs, *Echinococcus granulosus,* which is found as an adult in the intestine of a dog. It is no more than a third of an inch long, but there may be hundreds present in one dog. It is not difficult for a person to get the eggs when the association between dog and human is too intimate, since dogs often have them on their noses and tongues and seem to have a great desire to lick a person on the mouth. A small child can hardly avoid this show of affection on the part of his pet. Once inside the body the embryo bores through the intestine and finds its way to a suitable spot to encyst. It does not form the small cyst like the pork or beef tapeworms, however, but it produces buds and eventually a cyst as large as a cocoanut is formed that may have scoleces within numbering in the thousands. They are usually removed surgically. Since a dog very seldom has access to human flesh, it would seem that this is a case where the parasite reached the wrong intermediate host. However, cattle and sheep can also serve as intermediate hosts so the dogs are kept supplied from these sources.

Classification and Derivation of Scientific Words

Phylum Platyhelminthes (Gr. *platys,* flat; *helmins,* worm; refers to body shape).

Class A. Turbellaria (L. *turbo,* that which spins or whirls around; possibly refers to the fact that these animals when placed in water spin around as they settle down to the bottom).

Genus 1. Planaria (L. *planaris,* flat or plane; refers to body shape).

Class B. Trematoda (Gr. *trema,* hole or sucker; refers to presence of suckers which are on the flukes to attach them to parts of an animal body).

Genus 1. Clonorchis (Gr. *clon,* branch; *orchis,* testes; testes are branched).

species a. sinensis (L. *Sina,* China; locality where this species is found).

Class C. Cestoda (Gr. *cestos,* a girdle).

Genus 1. Taenia (Gr. *taenia,* a ribbon; refers to shape).

species a. solium (L. *solium,* throne; possibly refers to the appearance of the scolex).

species b. saginata (Gr. *sagina,* fatness; possibly refers to the fattened appearance of the ripe proglottids).

Genus 2. Dibothriocephalus (Gr. *diphyos,* twofold; *bothrion,* sucker; *kephale,* head; bears two suckers on its head).

species a. latus (L. *latus* side; possibly refers to the two suckers lying on either side of the scolex).

Genus 3. Echinococcus (Gr. *echinos,* spiny; *coccus,* berry; refers to the spiny appearance of the cyst due to the multiple scoleces).

species a. granulosus (L. *granulum,* grandular; the cyst appears to be granular).

REVIEW QUESTIONS

1. Distinguish between radial and bilateral symmetry.
2. Name and locate the six directions of a bilaterally symmetrical animal.
3. Tell how planaria changes its body shape.
4. Describe feeding in planaria.
5. Why are the excretory and digestive systems so extensively branched in planaria?
6. Distinguish between motor and sensory nerves.
7. Hermaphroditic animals produce both eggs and sperms yet they usually have some provision for transference of sperms from one animal to another. What biological advantage results from such exchange?
8. Describe fission in planaria.
9. How much power of regeneration is possessed by planaria?
10. How can a planaria live for months without food?
11. How do the eyes of planaria differ from the eyes of higher forms of animal life such as man?
12. Explain how flame cells function.
13. What do we mean when we say that planaria is a triploblastic animal?
14. How is the Chinese liver fluke spread from one person to another?
15. How does the life cycle of the sheep liver fluke differ from that of the Chinese liver fluke?
16. Name two ways by means of which the spread of the Chinese liver fluke could be stopped.
17. Why are proglottids considered to be separate animals in certain respects?
18. Name two ways in which the spread of the beef tapeworm can be stopped.
19. Why must there be such a great emphasis on the reproductive systems of the tapeworms?
20. Name three tapeworms which live in man's intestine and tell how each gets there.
21. How do tapeworms damage the body?
22. When taking medicine to eliminate a tapeworm from the body, why is it most important to see that the scolex is eliminated?
23. How does *Echinococcus granulosus* differ from other tapeworms in its effects on the human body?
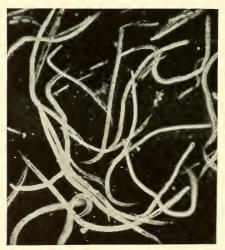
Roundworms—The Nemathelminthes

This phylum of worms includes those with a rounded body in contrast to the flattened body of the previous phylum, so they are commonly called the roundworms. The phylum name is derived from words meaning "thread worms" and, because of their long slender bodies, many of the smaller ones do closely resemble thread. They are among the most abundant of all animals, and there is hardly a spot on the earth that does

Courtesy General Biological Supply House

Fig. 11.1. Vinegar eels. These tiny roundworms are are often found in the scum that forms on vinegar. We have all, no doubt, eaten some of them in salads seasoned with vinegar, but, fortunately, they are not harmful in any way.

not contain roundworms. A little debris taken from the bottom of a pond will likely contain hundreds of tiny roundworms which can be seen under the microscope threshing around vigorously and apparently getting nowhere. Amoeba and paramecium cultures usually contain some of these and it is sometimes difficult to draw a student's attention away from these interesting creatures to study the protozoa. A spadeful of garden soil may contain millions of them; but, again, the aid of a microscope is needed to see them because of their small size. If you like

homemade pickles and other similar foods prepared with apple-cider vinegar it might be best if you do not examine the scum that forms on the top of the liquid, for you are very likely to find the same wiggling little worms. These are called vinegar eels and do man no harm. Since you, no doubt, have eaten many of them in the past, there is no reason that you should deny yourself these foods in the future. There is one species found in Germany that lives a life that some people would envy; they inhabit the mats upon which the mugs of beer are placed and live entirely on the beer that slops over edges of the mugs.

In addition to these very abundant free-living forms, the roundworms are, by far, the most abundant of the metazoan parasites. Some are plant parasites, crawling around among the cells, sucking the cell sap, and causing the plants to wither and otherwise interfering with their normal growth. Vertebrate animals usually carry from one to half a dozen species in their bodies at all times, with the exception of civilized man, who, by sanitation and medical vigilance, manages to avoid such a universal infection; yet there are comparatively few persons who have not harbored at least one of these parasites during their lifetimes, perhaps unknowingly.

The Large Roundworm of Man—Ascaris

As a type animal for this phylum, we will study *Ascaris* which is a large roundworm that lives in the intestine of man. It is probably the oldest known parasite of man because it is so large that it could hardly be overlooked when passed from the body, even by prehistoric people. It may be about a foot long and normally stays in the small intestine, but it seems to be a very inquisitive creature and sometimes crawls into the liver, pancreas, appendix, or occasionally all the way up the esophagus and out of a person's nose to his great horror, especially when he did not even suspect that he was infected. These worms eat the digesting food floating in the intestine and sometimes bite the intestinal wall and suck blood. They may become so numerous as to block the intestine and thus cause death unless removed surgically.

The life processes of ascaris show several advances over those of planaria. The **digestive** system consists of a tube that runs the length of the body with a **mouth** at one end and an **anus** at the other. The advantage of this arrangement over that in which a single opening had to serve as both a mouth and an anus has been discussed in the chapter on planaria. There is a **pharynx** just back of the mouth which pumps the digesting food through the **intestine** where absorption takes place. There seem to be no digestive glands present to secrete enzymes of diges-

tion since they, obviously, are not necessary, but other roundworms that have to do their own digesting do possess them. Egestion, of course, is through the anus. The absorbed food is spread over the body by a fluid in the body cavity around the intestine, so that there is no need for the extensive branching of the intestine as was found in planaria. This serves somewhat as a forerunner to a **circulatory system.**
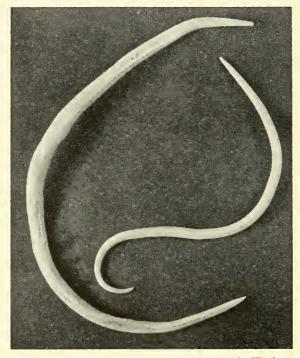

Photo by Winchester

FIG. 11.2. Ascaris, the large roundworm of man. Note the larger size of the female and the distinct crook at the posterior end of the male. Length of female, 9 inches.

Respiration is a little difficult to account for, because there would not be oxygen in any quantity in the intestine. Some of the worms that inhabit the small intestine get oxygen by sucking blood into their bodies which contains the oxygen that was absorbed from the person's lungs. Ascaris does not do this with any regularity, so it seems to derive its oxygen in the same manner as the anaerobic bacteria which live without any contact with the air. This is done by an incomplete breaking down of some of their food to produce oxygen necessary for the release of energy from the rest of their food.

Excretion is carried out by a pair of excretory tubes that run the length of the body on either side and unite and empty through a pore at the anterior end a short distance behind the mouth. The **muscular system** shows no noteworthy changes in comparison with planaria.

The **nervous system** consists of a nerve ring which circles the pharynx and two nerve cords running the length of the body as in planaria, but these two are dorsal and ventral rather than lateral. Connecting nerves circle the intestine at intervals and smaller branches are given out to all parts of the body.
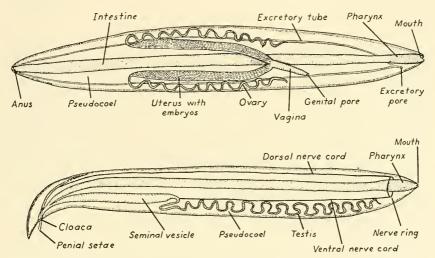
Fig. 11.3. Internal structure of ascaris; female above and male below. The excretory system is shown only in the female and the nervous system is shown only in the male; both are present in both sexes, of course.

The **reproductive system** is represented by organs similar to those found in planaria, but the one significant difference is the separation of the sexes. There are definite male and female ascaris and they can be recognized externally rather easily. The female is about a fourth of the body length longer than the male and somewhat thicker, and the male has a distinct crook at the posterior end with a pair of small hair-like projections called **penial setae** near the end of the crook. Because the sexes are distinct there must be at least two animals in a person's body before the infection can be spread to others. The male and female copulate in the intestine, and the female soon becomes an egg-producing machine with a daily egg production that would make the world's champion hen seem poor in comparison. Something like 200,000 eggs in twenty-four hours is a good estimate for a healthy ascaris female. These pass

from the body along with the feces and the main method of diagnosis for ascaris infection consists of an examination of the feces for the eggs. If a person has the worms, even a small sample of the excrement from his body will show many of these eggs. This examination is somewhat simplified if the fecal material is stirred up in some saturated salt water and allowed to stand a short time. The eggs will then float to the top, where they can be removed easily for microscopic examination, and the remainder of the material will settle to the bottom.

Ascaris infections are quite common in our southeastern states, especially in mountainous regions where a lack of sanitation allows these eggs which pass from the body to be spread where others may get them. There is no intermediate host and infection comes with ingestion of the eggs. Such an event might seem extremely unlikely, but examinations of school children in certain rural areas of Tennessee by the State Board of Health revealed up to 80 per cent infection. One explanation for this lies in the longevity and great resistance of the eggs. One worker found the eggs capable of causing infection after four years storage in an icebox, and others have been kept in 5 per cent formalin for a time without being destroyed. It is, therefore, a fairly simple matter for the eggs to be spread around where they may get on the hands of children, and also adults, and eventually into the mouth. When swallowed they reach the intestine where the embryos hatch out as tiny larval forms. A newly hatched ascaris larva is apparently not adapted for life in the strong digestive fluids of the small intestine and so for the first ten days of its life it lives in other parts of the body. First, it bores through the intestine and gets in the blood stream which carries it all over the body and it finally ends up in the lungs. There, it bores through the lung tissue into one of the many little air sacs found in the lungs. This breaking through the tissue causes a little bleeding and a blood clot is formed around the little larva. The presence of this foreign material in the lungs causes a person to cough and the blood clot containing the larva is coughed up. If the person coughs hard enough he may get it all the way up into the mouth where it may be spit out. On the other hand, a polite little "hack" is likely to bring it up only to the throat where it is immediately swallowed back down into the stomach and intestine and rapidly grows to its adult size and begins the vital process of reproduction.

If a person has ingested a large number of eggs and there is extensive injury to the lung tissue, a type of pneumonia may result which may be quite serious in nature. The adults living in the intestine do not seem to do the body great harm, but there will frequently be anemia and nervous disorders due to the absorption of their poisonous waste products.

There are a number of drugs which seem very effective against them such as oil of chenopodium and hexylresorcinol, so there is no excuse for a person tolerating the infection when the worms can be rather easily expelled.

The Hookworm

There is a much smaller roundworm which causes body symptoms that are much more serious than those caused by ascaris. This is the hookworm which gets its name from the hooked body of the male. The scientific name, *Necator americanus,* literally means American killer and a

Courtesy Army Inst. of Pathology

FIG. 11.4. Photomicrograph of the anterior part of a hookworm attached to the intestine. Note the part of the intestine extending down into the hookworm's mouth.

study of its depredations will justify the name. It lives in the small intestine, but does not absorb the digesting food like ascaris; instead it bites the intestinal wall and sucks blood and, since it moves around quite a bit, it does extensive damage to the intestine and there is quite a bit of bleeding at a spot after the worm has moved to another place. The excretory wastes of a number of these worms cause a general physical and mental retardation and a typical "shiftlessness" that, for many years, was characteristic of a great proportion of the population in many of our southern

Esophagus

Trachea

Lung

Inferior vena cava

Heart

Stomach

Small intestine (larvae grow to adults and live here)

Femoral vein

Human feces

Migrating larvae (enlarged)
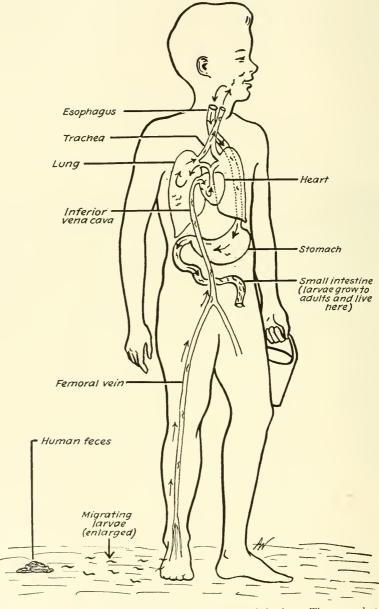
FIG. 11.5. Diagram illustrating method of hookworm infection. The eggs hatch in human feces passed from an infected person. The newly hatched larvae migrate in all directions. They then bore their way into the blood stream of any person that contacts them with the bare skin. They go through the veins to the heart, thence to the lungs, and are coughed up into the throat. They may be swallowed back down the esophagus, to the stomach, and finally to the small intestine where they grow into adults and live the rest of their lives.

states, where the proper conditions of moisture, temperature, lack of sanitation, and personal habits made the spread of this worm very easy. Today, it has been largely brought under control through a vigorous program of education and sanitation.

Its life cycle is identical to ascaris with the exception of its mode of entry into the body. When the hookworm eggs leave a human body they hatch into small larvae on the ground and are able to infect man by boring through his skin, the most common site being through the bare feet. There have been regions of our country, and are still some today, where shoes are considered an unnecessary luxury, and the larvae lurking in damp shaded soil have an excellent opportunity to grab hold of the skin when stepped on and to bore through. Once inside the body they are carried by the circulatory system to the lungs where they bore through, are coughed up, and swallowed, so that they end up in the intestine.
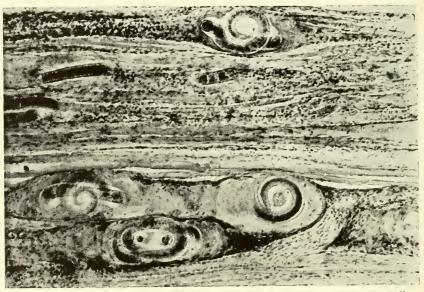
The Trichina Worm

The trichina worm, *Trichinella spiralis,* is another of the serious parasites of man, but it does not restrict itself to regions of the country where somewhat primitive living conditions exist. In fact it seems to be most abundant in the heavily populated eastern states and is just as prevalent in cities as in rural regions. Autopsies performed in this region reveal that about 27 per cent of all the people have had the infection during their lifetimes, with an average of the country as a whole being about 17 to 18 per cent.

This is another one of the parasites obtained from pork and, unfortunately, meat inspection is unable to detect the pork which carries it with any degree of certainty. The little larvae are coiled up in the meat and, since they are microscopic in size, it would require an extensive microscopic examination of the meat to detect them and, even then, cases of light infection could easily be overlooked, so thorough cooking of all pork to be eaten is the only sure way to avoid possible infection with *Trichinella.*

Once the tiny larvae reach the intestine they become active and quickly grow to adult size, which is only about three millimeters for the female and about half as long for the males. Within two or three days after being ingested they copulate and the males, their purpose in life having been completed, die and pass from the body shortly thereafter. The eggs hatch in the bodies of the females, and they deposit the living larvae in the lining of the intestine so there will be no chance that they will be carried from the body. These then find the blood stream and are

carried over the body to invade the voluntary muscles where the little worms wiggle around for a while and finally settle down and encyst. It is this working around through the muscles that causes the serious symptoms of this infection. A single female may deposit approximately 1,500 larvae in the intestine and when we consider that a good mouthful of heavily infected pork sausage may contain 25,000 encysted worms of which about half are females, we can understand how about 18 million larvae could be released in our bodies by the worms that we could ingest in one bite. The movements of the worms through the muscles cause

Courtesy General Biological Supply House

FIG. 11.6. *Trichinella spiralis* encysted in pork. If such pork is eaten without thorough cooking, the worms become adults in the body and produce young that work their way through the muscles causing a painful condition known as trichinosis.

extreme pain and cramps which may result in death if the infection is heavy enough. The females will die within two or three months so the disease will play out if you can survive these pains, but you will always carry the little encysted larvae in your muscles as a souvenir of your experience.

Since hogs do not have access to human flesh, we must still explain how the larvae happened to be in the hog muscle to complete the story. These larvae seem to be acquired primarily through an accidental cannibalism. When hogs are fed on garbage there may be some scraps of uncooked pork that have been discarded during the preparation of the

meat for cooking. If these scraps contain the encysted larvae, the hogs can readily become infected. Because of repeated cases of human infection, some regions require thorough cooking of all garbage before it is fed to hogs.

The Pinworm

One of the most widespread of the roundworms is the pinworm, *Enterobius vermicularis*. It is found in all parts of the world and is especially abundant among children in the United States. The adult worms, about half an inch long, live in the large intestine and the females have a habit of migrating down and laying their eggs around the anal opening. This causes an intense itching and desire to scratch so that children easily get the eggs on their hands and, thus, can reinfect themselves. The eggs make a direct trip through the digestive system and hatch and grow to maturity when they reach the large intestine. They live only a few weeks so, if reinfection can be prevented, they will disappear from the body within this period of time. It is very difficult to prevent reinfection, however, because the eggs are very small and light in weight and easily spread, so medical treatment to expel them seems to be advisable.

Perhaps this recital of the life histories of these common parasites has somewhat shocked the more squeamish of you, yet a knowledge of their life histories will help protect you from them. Certainly it would be more shocking to have them in your body than to read about them, and, no matter how fastidious you may be, you have no assurance that you will not have the opportunity to acquire some of them during your life.

Elephantiasis

One of the most repulsive diseases of tropical regions is known as **elephantiasis** in which certain parts of the body increase in size tremendously. An ankle may swell until it is as big as a person's waist; a single finger may enlarge until it is larger than the wrist; the male genital organs may swell until a man cannot walk. These symptoms are caused by an accumulation of small roundworms in the lymph spaces and the consequent interference with the free flow of lymph through these regions. This causes the lymph to accumulate and causes a temporary swelling which is followed by a growth of connective tissue that makes the swelling permanent. *Wucheria bancrofti* is the genus and species name of the worm causing this condition. The females may be about three inches long, but only about as thick as a coarse sewing thread, while the males are about half this length. They are found in great tangles in the

lymph spaces when infected regions of the body are cut open. After mating, the females release live larvae into the lymph because the eggs hatch before they are laid just as was the case with *Trichinella*. These tiny larvae are only about a hundredth of an inch long and are carried to the blood. Here they await the bite of a mosquito that might spread them to another person. In most parts of the world, the common *Culex* mosquito seems to be the intermediate host. After being sucked into the mosquito's body the larvae undergo further development and in a few days are ready to infect a second person.

The disease is known in only one locality of the United States, Charleston, South Carolina, but is quite prevalent in the West Indies, which lie not far from the Florida coast. Many of our service men became infected while on duty in the South Pacific and, since the *Culex* mosquito is so very abundant in the United States, many have expressed concern that it might get started here. However, the fear seems unfounded, because the larvae seem to require the particular combination of heat and humidity found in the tropics in order to complete their cycle. The disease requires a year or more to develop and, if discovered in its early stages, the great enlargement of body parts can be prevented by the injection of drugs that kill the worms.
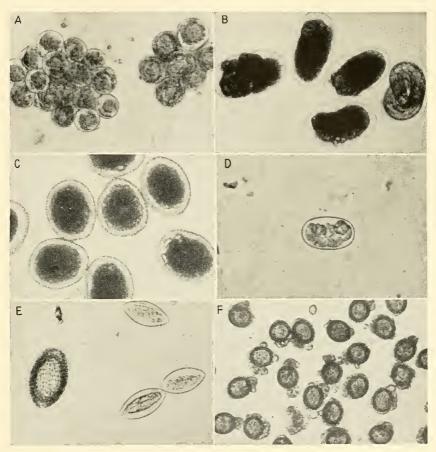
The Hair Worm

A very popular superstition that has been handed down from generation to generation is that a horse hair, if placed in water, will turn into a snake. Many a child has followed these directions and carefully watched the hair for signs of life. The fact that there never has been one that came to life does not seem to discourage the spread of the superstition. The hair worm, *Gordius,* seems to be the culprit that gave origin to this idea. This worm is very slender and long, brown or black in color, and does very closely resemble a long hair that might fall from a horse's mane or tail. However, they are very much alive and the sight of one of these worms wiggling in a puddle could easily lead to such false deductions. The hair worms are parasites on aquatic insects and their larvae enter the bodies of insect larvae and are later carried to other ponds as the adult insect matures and flies away.

Some Principles of Parasitology

The term parasite has a bad connotation in the English language. We frequently use it in reference to persons who attempt to go through life at the expense of others. We should remember, however, that all forms

of life that do not have chlorophyll must depend upon other forms of life for their food supply. Hence, the parasites are distinguished from the others merely by the fact that they derive their nourishment from others while the organisms furnishing the nourishment are still living. The

FIG. 11.7. Variation in the eggs of parasites. Because of the structural differences in the eggs it is possible for a parasitologist to determine the kind of parasites in an animal's body by examination of the eggs in the feces or other body excrements. A. Dog tapeworm, *Dipylidium caninum*. B. Goat lung worm. C. Dog hookworm. D. Dog tapeworm, *Taenia pisiformis*. E. Sheep thorn-head worm. F. Dog ascaris.

fact that they cause injury, disease, and sometimes death to the host which furnishes the nourishment is an unfortunate incident accompanying the habits of the parasite. So far as the parasite is concerned, it would be better if the host remained in the best of health, for in this way the parasite

will thrive best. If it is an internal parasite, it will die when the host dies. A well-adjusted parasite, therefore, is one that does not do too much harm to its host. As an example, most dogs carry several different kinds of worm parasites in their intestines; yet they show no great loss of vitality because of the presence of these worms in most cases.

When there is an association which is so well adjusted that the host is not harmed at all, we do not call the organism a parasite, but refer to it as a commensal. Thus, *Endamoeba coli* would be considered as a commensal since it lives in the human intestine and derives its nourishment from food which we supply, but we are not harmed by its presence. Finally, when an association between two living things is not only peaceful, but positively beneficial to both, it is referred to as symbiosis. You may recall the case of the Portugese man-o-war and *Nomeus* as an example of this type of association.

All parasites have one characteristic in common—they are highly specialized for the type of existence they lead, and there are very few parasites that are able to live without their specific hosts. They must make so many adaptations to accommodate themselves to a parasitic existence that they lose the characteristics which enable them to exist as free-living animals or plants. Let us consider ascaris as an example. It lives in the intestine and cannot obtain free atmospheric oxygen, so it has anaerobic respiration. It has lost any digestive glands that its ancestors may have had, for it needs no enzymes while it is living in the presence of digesting food. It may seem strange that ascaris is not digested by the enzymes which are digesting the food around it. Studies of this worm show that if one dies and is lodged in the intestine so it is not expelled, it will be digested. This shows that there is something about the physiology of the living worm that resists digestion. It produces enzyme-neutralizing substances which render the enzymes ineffective on it. These substances are somewhat like the antitoxins produced by our own bodies to neutralize the toxins of disease germs and other foreign bodies that may get into our bodies. This is one reason why internal parasites are usually specific as to their hosts. The intestinal secretions of different animals may vary; and, when a parasite produces the neutralizing agents for one animal, it might find an entirely different set necessary for another animal. We, no doubt, eat many eggs and larvae of parasites which inhabit other animals, but we are not affected because the young parasites are digested by our enzymes. The gametes of the human malarial parasites can withstand the digestive juices of the *Anopheles* mosquito, but not those of the *Culex* mosquito. The ascaris found in man shows no distinguishable morphological difference from that found in pigs, but the human ascaris will not infect the pig and vice versa.

This same principle holds true for the parasites of the blood stream and other parts of the body. There are physiological differences in the blood and other body fluids that make it difficult for parasites to be adapted to different species of animals. The larvae of the dog hookworm sometimes enter the human skin. In the unnatural surroundings, however, they do not find their way to the lungs and thence back to the intestine as they would in the dog. Instead they wander around under the skin, creeping along. Such an infection is known as "creeping eruption." They eventually die or their death can be hastened by freezing them with a spray of ethyl chloride.

Classification and Derivation of Scientific Words

Phylum Nemathelminthes (Gr. *nema,* thread; *helmins,* worm; refers to the thread-like nature of many of the roundworms).

Genus A. Ascaris (Gr. *ascaris,* an intestinal worm).

species 1. lumbricoides (L. *lumbricus,* earthworm; refers to the resemblance of this species to earthworms).

Genus B. Necator (Gr. *necator,* killer; this small hookworm frequently is a killer).

species 1. americanus (Eng. *American;* refers to location).

Genus C. Trichinella (Gr. *trichos,* hair; refers to the hairlike appearance of this worm).

species 1. spiralis (Gr. *spiralia,* a coil; refers to its coiled condition as a larva in muscle).

Genus D. Wucheria (From Dr. O. W. Wucherer).

species 1. bancrofti (named from man, Bancroft, who did pioneer work with the filaria worm).

Genus E. Enterobius (Gr. *enteron,* intestine; *bios,* life; spends its life in an intestine).

species 1. vermicularis (L. *vermiculus,* a little worm).

Genus F. Gordius (L. *gordius,* a knot; these hair worms may sometimes be found tangled in knots).

REVIEW QUESTIONS

1. How is ascaris able to exist in the absence of oxygen in the intestine?
2. Why are digestive glands unnecessary on the intestinal tract of ascaris?
3. Why is the extensive branching of the digestive and excretory systems, such as was found in planaria, not necessary in ascaris?
4. Why is it necessary for the female ascaris to lay such a large number of eggs?
5. Trace the journey of the ascaris larva through the body.
6. How do the feeding habits of the hookworm differ from ascaris?
7. Trace the life cycle of the hookworm.

8. Explain the physiological effects of *Trichinella* infection.
9. Trace the life cycle of the pinworm.
10. Give the physiological cause of elephantiasis.
11. What popular superstition is associated with the hair worm?
12. Explain how hogs and people become infected with *Trichinella*.
13. Many of those who get ascaris infection also develop pneumonia. Why is this?
14. Explain how commensalism differs from parasitism.
15. Why is it said that an ideal parasite does not do much harm to its host?
16. How can parasitic worms live in the intestine without being digested by the enzymes which are present around them?
17. In what ways has the tapeworm become so specialized as a parasite that it could not exist as a free-living form?
18. Many people are bitten by mosquitoes carrying the sporozoites of bird malaria, yet they do not develop the disease. What is the probable explanation for this?

12

Segmented Worms—The Annelids

If you like to go fishing you surely have some acquaintance with at least one member of this phylum. The earthworm, which is the most abundant genus in this group, is noted for its ability to entice fish to bite, and no picture of a young American going out to fish would be complete without a pole and a can of worms. However, serving as fish bait is not, by any means, the greatest economic importance of the earthworm as we shall soon learn. Worms in this phylum are characterized by segmented bodies. The phylum name means little ring, and as you look at one of these worms you will see that the segments resemble a series of little rings joined together to make the entire animal.

Because of its abundance, economic importance, and the typical arrangement of organs, we will choose the earthworm, *Lumbricus terrestris,* as a type animal for the phylum. Earthworms may be found almost everywhere that there is moist soil, and their tremendous value to agriculture can hardly be overestimated. They have a habit of eating the dirt as they crawl through it when it is closely packed and it passes through their bodies to be left behind. This makes the soil loose and porous so that plant roots can easily penetrate it and at the same time makes it spongy so that it will hold the rain that falls. Also, the wastes from the earthworms' bodies add to the fertility of the soil, and it is doubtful if the farmer could find a better friend than the earthworm.

Life Processes of the Earthworm

The life processes of the earthworm show many interesting developments and, since many of these are similar to those of higher animals, we shall survey them in some detail.

Respiration is carried on by direct absorption of oxygen through the skin, and carbon dioxide is given off from the same area. The skin must be continually moist or this exchange cannot take place and the worms will suffocate. The earthworms move up or down in the soil according to the region where the conditions of moisture are best suited to their needs. They go deep in dry weather and come up when the soil becomes saturated at the lower levels. They may even leave their

burrows in the ground and crawl around on the surface on damp nights. If you will take a flashlight and go out on the campus some dark night about midnight when it is pouring rain you may see some earthworms crawling around on the surface. It is a little more convenient and considerably drier to wait until the next morning and then see some of them on the surface that failed to get under before the sun came up and suffocated as their skins dried. Normally, when the rain stops and the air becomes a little dry, the worms will crawl back in the ground by eating their way down. Those which succeed leave little castings of dirt on the surface as evidence of their prowling, while those that find themselves on a concrete walk are likely to have considerable difficulty trying to eat a hole through it to get in the ground beneath. Their dead bodies can be seen on the walks as an evidence of their unfortunate predicament.

It might be difficult to convince a golfer that earthworms are such nice and beneficial creatures after his ball has been deflected from the hole by earthworm castings on the green, and many golf courses put poison in the ground to prevent such an occurrence that may loom as catastrophe at the moment.

Lumbricus has the best developed **digestive system** that has been studied. Some of its nourishment comes from the digestion and absorption of the decaying organic matter that is present in the soil which the worm eats as it moves about. However, it has another and more efficient method. The **mouth** is at the anterior end and bits of leaves or other food may be ingested with the aid of the **pharynx** which is next in line. The pharynx is muscular in nature and capable of expansion and contraction, so the earthworm places its mouth over the food and the pharynx suddenly expands, thus creating a suction that pulls the food in. This is not such a strange method of ingestion since many people use the same principle in getting soup into their mouths. The food is then forced from the pharynx and down the **esophagus** by rhythmic contractions of the walls which are called **peristaltic** movements. These same movements are found in the human alimentary tract and are involuntary in nature. Once a mouthful of food reaches your pharynx, or throat, it is seized by these contractions and carried on down your esophagus to your stomach even though you may change your mind and decide that you do not want to swallow it. The earthworm empties the food into the **crop,** which is a storage chamber from which the food is released in small portions to the **gizzard.** Birds and earthworms have something in common; neither of them have teeth and both of them have a crop and a gizzard. The gizzard makes up for the lack of teeth by grinding the food which was swallowed whole at the mouth. Sand grains are in the gizzard of the earthworm to aid in the grinding process, and birds eat

gravel for the same purpose. Once properly ground, the food is then passed to the **intestine** where enzymes are poured on it from the intestinal wall. Digested food is then absorbed by the blood vessels, which liberally supply the intestine, and is thus carried to all parts of the body. The indigestible part is expelled through the **anus.**

The area where absorption of food can take place is increased because the intestine folds downward from the dorsal surface to form a projection
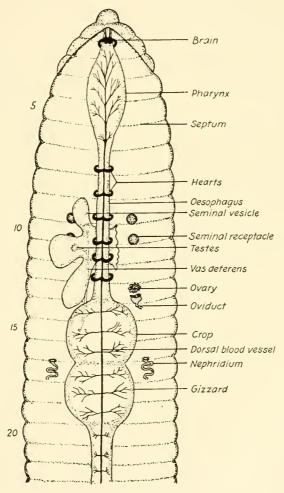

FIG. 12.1. Dorsal view of the internal organs found in the anterior region of the earthworm. The nephridia are shown in only one segment; actually they are found in each segment. The seminal vesicles, including the testes and vas deferens, have been removed on the right side to show the organs beneath.

into its interior, which is called a **typhlosole.** This makes the intestine much more efficient for its length than it would be otherwise.

The earthworm has a **circulatory system,** and one of the most striking things about this system is the presence of ten hearts. These hearts are not nearly so complicated as the hearts of the vertebrate animals, but they are organs which pump blood and this is the main function of any heart. In addition to the hearts, there are two major blood vessels with a number of smaller branches and capillaries which carry the blood to all parts of the earthworm's body. The blood is red in
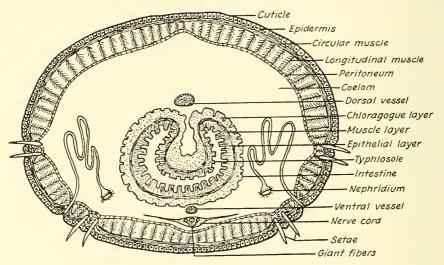
FIG. 12.2. Cross-section of the intestinal region of an earthworm.

color due to the presence of **hemoglobin** which is the oxygen-absorbing part of the blood, but microscopic examination reveals that the hemoglobin is not contained in corpuscles as it is in the vertebrate animals, but is dissolved in the plasma.

If you put a living earthworm under a binocular microscope, or study it with a hand lens, you will be able to see the blood flowing through the **dorsal vessel** which lies near the dorsal surface. It moves in an anterior direction and is carried along by peristaltic contractions of the vessel which closely resemble the contractions of the alimentary tract previously described. This blood is on its way back to the hearts after a circuit around the body and there is little pressure left from the heart beats so these contractions help it along. It flows down into the five pairs of **hearts** which are nothing more than enlarged, contractile blood vessels with valves at either end. These vessels allow the blood to flow in from

the dorsal vessel, causing them to expand and then force the blood out into the **ventral vessel** when they contract. The blood flows posteriorly in the ventral vessel which gives off branches that lead to all parts of the body and eventually ends up in **capillaries,** which are a network of fine blood vessels where the absorption of some products and the giving up of others through the principles of osmosis and diffusion take place. Larger vessels again collect the blood at the other end of the capillaries and take it to the dorsal vessel and the cycle is repeated. Circulation is aided by the movements of the **coelomic fluid** flowing in the cavity which lies between the intestine and the muscle layer and which is given the name **coelom.** This fluid is colorless and, therefore, contains no hemoglobin like the blood, but otherwise closely resembles it. It can move freely from one segment to another even though there are internal partitions, called **septa,** which separate the segments, but each septum is perforated in its ventral portion.

The **excretory system** consists of a pair of **nephridia** in each segment except the first three and the last. Each nephridium consists of a little funnel surrounded by cilia which connects to a coiled tube that runs backward and empties to the outside through a small pore on the ventral surface, but lateral to the middle of the body. Excretory waste is swept up by the cilia from the coelomic fluid and carried down the funnel and into the coiled tube. There additional waste may be absorbed from the blood through the capillaries which line the tube, finally to be emptied to the outside.

Did you ever "worm" your way along the ground? Our soldiers, during the war, in many instances, probably felt a close kinship to the earthworm as they inched over the ground in worm-like motions to avoid enemy fire. You do not travel very fast, but you eventually reach your destination if you keep at it long enough and you realize the importance of a well-developed **muscular system** in the earthworm. This system consists of circular and longitudinal muscle fibers which are able to extend and to shorten the animal's body length, respectively. There are four pairs of tiny bristles, the **setae,** that stick out from each segment. These can be controlled by small muscles to each, although they usually point backward. While in this position the setae prevent the worm from slipping backward, so as it shortens and lengthens its body, it moves forward. By simply reversing the direction of the setae, so they point forward, the earthworm can move backward by the same body movements. If you have ever tried to pull an earthworm from a hole you realize the great power of traction that these setae give, for you can pull the worm in two without succeeding in your endeavor. If you pull an earthworm

through your fingers you can easily tell the direction in which these little bristles point by the traction on your fingers.

The **nervous system** of the earthworm is organized very much like that of the higher animals, including man. There is a **brain** at the anterior end of the body and a **nerve cord** running the length of the body giving out nerve branches at different levels that run to all parts of the body. Some of these are **sensory nerves** and bring impulses only from sense organs to the nerve cord and continue up the cord to the brain. Others are **motor nerves** and lead from the brain and nerve cord out to the muscles and stimulate them to react. However, in the earthworm, the nerve cord is on the ventral rather than the dorsal body wall and the reactions are more or less of the reflex type with the brain having com-
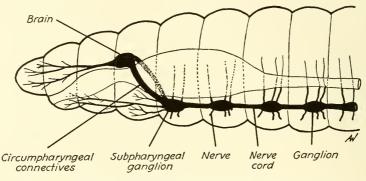
FIG. 12.3. Diagram of the central nervous system of the earthworm as seen from the side and slightly above with the left body wall removed. The anterior part of the digestive system is shown in outline to indicate relative positions of the organs.

paratively little to do with correlating the body reactions. A cross-section of the nerve cord will reveal three **giant fibers** in the dorsal region of the cord. These fibers contain nerves running the length of the body and connecting the different segments, so that they work in a coordinated manner, and strong stimulation brings response from all segments even though the brain has been removed. This is possible because each segment contains an enlargement of the nerve cord called a **ganglion** which acts somewhat like a little brain for that segment and makes the proper connections for response to stimuli. An earthworm can be cut into several parts and each part will go right on crawling around for a time and reacting to stimuli much as if nothing had happened, for the nerves in the giant fibers connect the different ganglia of each part together and give it coordination.

In higher forms of animal life the brain assumes a much greater control over the body and the reflexes from the spinal cord level are much

more limited, but if you have ever watched a chicken hop around after its head had been chopped off you surely know that these reflexes are found in more advanced animals. However, there is nothing like the giant fibers to give the coordination found in the earthworm.

Reproduction in the earthworms is very interesting. They are **hermaphroditic,** but have **copulation** with a mutual exchange of sperms in a manner that is somewhat similar to that in planaria. The **testes** are contained within the large **seminal vesicles** that extend from segments nine to thirteen and the two **vasa deferentia** lead back from these to a pair of external openings in segment fifteen. The female organs consist of a pair of **ovaries** in segment thirteen, a pair of **oviducts** which open

Courtesy General Biological Supply House

Fig. 12.4. Copulating earthworms. This picture was made outdoors on a rainy night by flashgun.

in segment fourteen, and two pairs of **seminal receptacles** in segments nine and ten.

During copulation two worms come together facing in opposite directions with their ventral surfaces in contact. The anterior ends of their bodies become fused together by a layer of mucous secretions so that the openings of their sex ducts are fairly close together. Sperms are discharged from the openings of the vasa deferentia, and pass down two pairs of grooves in the slime until they come to the openings of the seminal receptacles which they enter. It is a mutual exchange with each worm receiving sperms from the other. When insemination is completed the worms separate.

Later a swollen, band-like portion of the body, called the **clitellum,** which occupies segments 32 to 37, secretes a series of cocoons. Each cocoon slides over the anterior end of the earthworm and, as it passes the openings of the oviducts, eggs are laid in it. Then, as it passes the

pores of the seminal receptacles, sperms which have been received from the other worm are discharged and fertilize the eggs. The cocoon passes over the head and the ends close up tightly. It is left just beneath the surface of the ground by the worm. After completing their embryological development, the young worms crawl out of the cocoon (only one develops in each capsule in *Lumbricus terrestris*).

There is no asexual means of reproduction, but the power of **regeneration** is still possessed to a great degree even though diminished because of the greater specialization of cells in the earthworm's body. If an earthworm is cut in two between segments 15 and 18, the head piece will regenerate a new tail and the tail piece, a new head. If the cut is made posterior to segment 18, the tail piece cannot regenerate a new head, but instead usually develops another tail to form a worm with a tail on either end. This earthworm can very easily take care of egestion, but is at a loss for a place of ingestion and must slowly starve to death.

As in planaria, grafting is possible and an exceptionally long worm can be produced by grafting the posterior end of one worm onto the end of another earthworm, or a short one can be made by cutting several inches out of the center of one and grafting the two ends together. Curious two-headed or two-tailed monsters can be made by grafting together appropriate parts of several earthworms.

A Marine Annelid—The Clam Worm

The clam worm, *Neanthes*, is representative of the many marine annelids. This worm lives in the sand of shallow water near the shore line of many of the sandy beaches of the world. It burrows down into the sand, leaving only its head and tentacles protruding. Whenever some small water animal ventures too close to this innocent-looking protrusion, the clam worm may throw out its proboscis, grasp the animal, and pull it down into the burrow where it will be devoured. In external appearance the clam worm differs rather strikingly from the earthworm because of the presence of a row of paddle-like **parapodia** on each side of the body. There is a pair of these appendages on each segment. They are used in swimming and also to keep a current of water flowing through the burrow when the animal is at rest. This is necessary for proper respiration.

The body systems of the clam worm are very much like those of the earthworm except for reproduction. The clam worm has separate sexes, and the reproductive cells develop from the wall of the coelom in the posterior region of the body. During the reproductive season this por-

tion of the body becomes greatly swollen. As the sexes mingle in an annelid courtship these swollen regions burst open, liberating the sperms and eggs, and fertilization takes place in the open water. The worms then usually die, but in some species the uninjured anterior end may
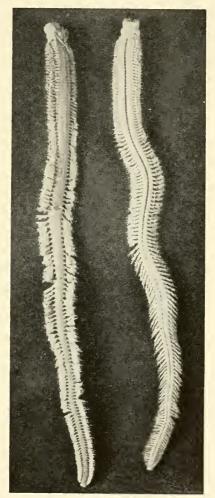
Fig. 12.5. Neanthes, the clam worm. Dorsal and ventral views.

regenerate a new posterior and life continues. In one species of marine annelid, the palolo worm of the South Seas, the posterior end of the animal breaks off and goes swimming to the surface, leaving the anterior end which begins regeneration of its lost posterior. This repro-

ductive process always takes place on the first day of the last quarter of the October-November moon. At this time the surface of the water near the shore may be filled with these swimming worm segments. Natives of these regions have learned of this and gather these in large numbers and have a feast.
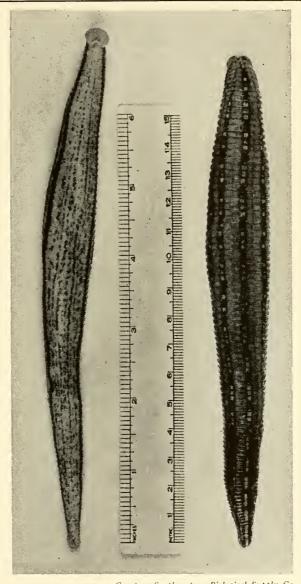
Parasitic Annelids—The Leeches

"Tight as a leech" is an expression used to indicate a very high degree of adhesion and any one that has tried to pull a leech off his body can well appreciate how tight this can be. Leeches are another of the segmented forms and have adapted themselves to a parasitic existence. They do not live in the bodies of other animals like many of the flatworms and roundworms, but suck blood through the outer skin of their hosts. Thus, they are **ectoparasites** rather than endoparasites like the others. If you put a living leech in an aquarium it will attach itself by a posterior sucker, and if you put your finger in the water it will stretch and wave the anterior portion excitedly in an effort to reach the finger. If it succeeds it will attach itself to your finger by the anterior sucker and release its hold at the posterior. There are three sharp teeth on the mouth within the anterior sucker and the skin is punctured by these teeth which are so sharp that there is usually no pain at all. Then the leech will gorge itself on blood, sucking in about three times its body weight if undisturbed. It will then drop off in a stupor and will not need to feed again for several months.

The practice of medicine was, at one time, spoken of as "leechery" because the doctors always carried a supply of large leeches in their little black bags. There is one leech that is well adapted to their purposes and it is still called the medical leech, *Hirudo medicinalis*. It is about four inches long and capable of ingesting a considerable quantity of blood. When a person was sick, it was believed that there was an upset balance between the body fluids and, by removing some of the blood, the balance could be restored and health would return. The leeches were a very convenient method of accomplishing this, which accounted for their popularity. More recently, the colorful barber shops of the early part of the century kept a supply of leeches on hand and, when a man got a black eye, or other conspicuous black and blue spots on his body, a lean hungry leech was applied to the skin and the discolored blood was sucked out. This practice has not entirely disappeared today, and it is possible to buy these large medical leeches at some drug stores for this purpose.

A particularly vicious land leech occurs in some densely vegetated tropical regions where the rainfall and humidity of the air are great

FIG. 12.6. Leeches. Large specimens from China extended to their length.

enough to allow them to live out of the water. A person walking through jungle regions where these abound must be careful to pick these leeches off when they become attached to his skin or he will lose an appreciable quantity of blood. There are even some cases where

death has resulted from such loss of blood when a person has been injured and unable to keep these leeches off his body. A few of these are found in the Everglades of south Florida. In North Africa, Asia Minor, and China there is a variety of leech known as the horse leech, so called because it often attacks the pharynx and nasal passages of horses. The leeches enter the nose or throat of the horses when the horses drink from pools and streams where the leeches live. Man may also get them by drinking this water. If he swims in the infested streams, the leeches sometimes enter the urinary passages where they may hang on for months.

Classification and Derivation of Scientific Words

Phylum Annelida (L. *anellus,* a little ring; the body of these worms seems
      to be made of a number of little rings joined together).
     Genus A.   Lumbricus (L. *lumbricus,* earthworm).
       species 1.   terrestris (L. *terrestris,* the earth; refers to the habitat of
         the earthworms).
     Genus B.   Neanthes (Gr. *neanikos,* youthful).
     Genus C.   Hirudo (L. *hirudo,* leech).
       species 1.   medicinalis (were once used by doctors to draw blood
         from patients).

REVIEW QUESTIONS

1. What activities of the earthworm make it economically valuable?
2. What is the function of the pharynx, crop, gizzard, and typhlosole in the earthworm?
3. Where is the hemoglobin found in the earthworm's blood? How does this compare with the blood of vertebrates?
4. Explain excretion in the earthworm.
5. How can an earthworm move either backward or forward by the same body movements?
6. Trace a nerve impulse from a sense organ to a muscle.
7. Compare the functions of the seminal vesicles and the seminal receptacles.
8. Explain the meaning of the term "hermaphroditic."
9. Discuss the extent of regeneration in the earthworm.
10. How is Neanthes conspicuously different from the earthworm in morphology?
11. What is meant by the terms ectoparasite and endoparasite?
12. Explain the method of copulation in the earthworms.
13. How does an hermaphroditic animal benefit from cross-fertilization?
14. Describe the method of cocoon formation and egg laying in the earthworm.
15. How have leeches been used in medicine?
16. Compare the method of reproduction in Neanthes with that found in the earthworm.
17. What systems of organs are present in the earthworm that were not found in ascaris?
18. In which direction does the blood flow in the dorsal and ventral blood vessels of the earthworm?

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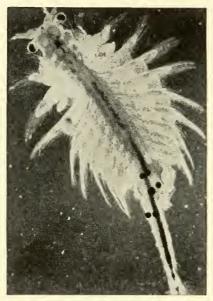
Animals with Jointed Legs—The Arthropods

This is a very extensive phylum including such commonly known animals as crayfish, crabs, shrimp, spiders, scorpions, centipedes, and insects.

We commonly think of the vertebrate animals as being the most successful and dominant of all the animal groups, yet, if the Arthropoda had the power of reasoning and could communicate their thoughts, they would probably claim this distinction. Furthermore, they would have very good arguments in support of their claim. They could show that over half of the species of animals that have been named and classified are arthropods, so, if success is measured in the diversity of types within the phylum, we could not dispute their claim. They could point out that arthropods are found everywhere that vertebrate animals are found and in many places where vertebrates cannot live. They may be found at the equator and in the arctic regions; they may be found flying high in the air and in the depths of the ocean; they inhabit the humid jungles and the dry sandy deserts. No extreme of environment seems to discourage them. They are the only animals that have been able to adapt themselves to the highly concentrated salt water of inland lakes having no outlet to the ocean, such as the Great Salt Lake and the Dead Sea. The Great Salt Lake contains about 27 per cent salt and is so dense that a person's body floats on it like a cork, yet it contains many little shrimp which spend their entire existence in this concentrated solution. Therefore, when the point of adaptation to environment is brought up, we must concede the advantage to the arthropods. Finally, it could be stated that there is no other group of animals on the earth so well armed for offense and defense. It is true that man, as one of the vertebrates, has been able to forge steel into terrible weapons of destruction, but the arthropods have forged their weapons from their own bodies and they are highly efficient and always ready for use. Of course, there would be some arguments in favor of the vertebrates, such as larger size and greater development of the brain and its functions. In the final analysis, however, we would have to conclude that the arthropods are at least the equal

of the vertebrates in success as a group, although they have followed a different pattern of development.

Because of their great numbers and wide distribution, it is evident that this group of animals is of considerable economic importance to man. They are probably more important than any other phylum. On the harmful side, they are serious competitors for our food supply; we must constantly fight some of them in order to secure the food for our-

Courtesy General Biological Supply House

FIG. 13.1. A brine shrimp from the Great Salt Lake. Although this lake contains salt in a concentration of about 27 per cent, this little shrimp has adapted itself to live in this extreme environment.

selves. They spread serious diseases which cause untold human suffering and death and make some parts of the earth uninhabitable by civilized races of man. Many of them have bites and stings that are unpleasant, to say the least, and, in some cases, serious. On the beneficial side, they provide us with quantities of food, medicine, clothing, and chemicals; they kill many of our enemies, including some in their own group; and they cross-pollinate many of our important plants. Thus, while we have a difficult time getting along with the arthropods, we would also have a hard time trying to get along without them.

Characteristics of the Phylum

The phylum name, Arthropoda, comes from Greek words meaning **jointed feet** and this is one of the most distinguishing features of the group. The feet, or legs, consist of a series of articulating joints which may be highly modified for specialized functions, such as swimming, respiration, obtaining food, etc. Members of this phylum have **segmented bodies,** such as are found in the annelids, but the segments are not all similar to one another like the annelids, but may be fused or modified to meet specialized needs. They have an **exoskeleton** of **chitin** which
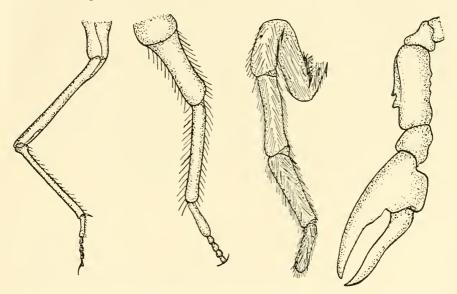
FIG. 13.2. Legs of arthropoda, showing the jointed condition characteristic of this phylum. From left to right they are the legs of a praying mantis, roach, spider, and crayfish.

is a very efficient skeleton. The term skeleton is commonly associated with an assortment of bones including a skull, ribs, vertebrae, and arm and leg bones; yet the outer covering of a grasshopper is just as much a skeleton even though it is found on the outside of the body. This is called the exoskeleton, which has its muscles inside, as contrasted to the **endoskeleton,** which has its attached muscles on the outside. Both serve their purpose very well, but there are certain advantages and disadvantages of each which might be considered.

The exoskeleton has a great advantage in protection. With the soft body parts internal to the skeleton they are much better protected than

when some of them are exposed to injury on the outside of the body. However, the endoskeleton has an important advantage in growth; the skeleton and the body parts can grow together, so the skeleton places no limitation on the size of the animal. The exoskeleton, on the other hand, incloses the remainder of the body and restricts the room that is available for growth. Some of the arthropods partially avoid this disadvantage by shedding their skeletons completely, in a process called **molting,** and then growing larger ones for increased size. This method has its drawbacks, however, and even with molting the body size is definitely limited. Since, in general a large animal has an advantage over a small one, this gives a point of advantage to the animals with an endoskeleton. We may well be thankful that we have this advantage in size, else we would not have a chance in competition with the arthropods. Imagine our consternation if we should find spiders as big as tigers lurking in dark places ready to pounce on us when we came near. Suppose there were wasps as big as buzzards that could zoom down out of the air and pierce us with a dagger-like sting that almost certainly would be fatal. Huge ants traveling in packs like wolves could terrorize an entire countryside. With all our modern weapons and ingenuity we would probably have little chance to survive attacks from such large arthropods with their protective armor and highly specialized weapons. In their present small size they can still give us considerable misery.

Class—Crustacea

This class name means hard shell and refers to the hard, crustlike exoskeleton found among members of this group. They are also characterized by a large number of paired appendages which typically are branched into two terminal portions. This is called a **biramous** type of appendage. They use gills for respiration, although a few of them live on the land and absorb their oxygen from damp air circulating over the gills. They have a body composed of many segments, as do all arthropods, but these are somewhat combined to form two or sometimes three main body parts. There are about 20,000 species of Crustacea ranging in size from tiny microscopic water fleas to huge crabs that have a leg spread of ten or twelve feet.

We will study the crayfish, *Cambarus,* as a typical representative of this class as well as the phylum as a whole. The name crayfish is the common name of this animal, as found in books, but the names crawfish and crawdad are more commonly used in referring to them. They live in fresh water and seem to prefer ponds and sluggish streams where the bottom is somewhat muddy. Many a child has spent happy hours "fish-

ing" for crawdads with a piece of bacon tied on a piece of string. The animal will grab the bacon with its pincers and, with just the right degree of pull on the string, will hold on until it is out of the water. Their abdomens or "tails" contain edible white meat, and they are often caught in large numbers for human consumption.

FIG. 13.3. Crayfish burrows. When the water level is not far under the surface, crayfish sometimes build burrows down to the water. In some sections of the country this creates quite a problem by weakening and allowing leakage from dams and levees.
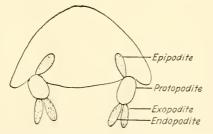
FIG. 13.4. Diagram showing the location of the parts of appendages of the crayfish. Not all appendages have all of the parts listed.

The appendages of the crayfish are diversified to meet a number of different needs, although in the embryo they all arise according to the same plan. We can think of the crayfish in its very early embryonic condition as being somewhat like the clam worm with each segment bearing a pair of appendages. The first four segments fuse to form the

head and the next eight to form the thorax. The head and thorax are so closely connected that they form a single part of the body, the cephalo-thorax. The final six segments form the abdomen. Thus, there are eighteen segments to the whole body; but, since there is an additional pair of appendages, the antennules, which are apparently not associated with a segment, there is a total of nineteen pairs of appendages. The true appendages in the embryo are all of the typically **biramous** type consisting of a basal portion attached to the body, the **protopodite,** which branches into an outer branch, the **exopodite,** and an inner branch, the **endopodite.** As development proceeds, however, the appendages are modified in various ways, each appendage becoming adapted to perform a particular function. In the adult stage they exhibit a great variety of shapes and sizes due to these modifications. Some of the branches may be greatly reduced or even lacking entirely, and some appendages have developed an entirely new attachment, the **epipodite,** which projects dorsally from the protopodite. The accompanying drawings illustrate the diversity in structure that exists between the different appendages. A brief listing of their uses will illustrate their diversity of function.

Antennule—two jointed filaments; touch, taste, equilibrium. This is not a typical appendage and does not represent a segment according to the latest research.

1. **Antenna**—a jointed filament with excretory pore in basal seg-ment; touch, taste.

2. **Mandibles**—crushing food.

3. **First maxilla**—small and delicate; helps guide food to the mouth.

4. **Second maxilla**—modified into a bailer, epipodite present.

5. **First maxilliped**—exopodite, a many jointed filament, epipodite present; taste, touch, holds food.

6. **Second maxilliped**—bears a gill, endopodite coarse, exopodite slender; touch, taste, holds food.

7. **Third maxilliped**—bears a gill, endopodite much larger than ex-opodite; touch, taste, holds food.

8. **First walking leg,** or cheliped—bears a gill, exopodite absent, distal two joints form a powerful pincher; catching animals, cutting them up, and defense against enemies.

9. **Second walking leg**—bears a gill, exopodite absent, walking and grasping with its small pinchers.

10. **Third walking leg**—same as second leg.

11. **Fourth walking leg**—same as third leg, but pinchers are absent.

12. **Fifth walking leg**—same as fourth leg, but may be used to clean abdomen.

13. First swimmeret—biramous in male, but endopodite and exopodite fused together to form an organ for use in copulation; reduced and nonfunctional in female.

14. Second swimmeret—biramous—used in copulation in male, but small and nearly functionless in female.

15. Third swimmeret—creates a current of water that may enter the gill chamber, and in female serves for attachment of eggs.

16. Fourth swimmeret—same as third.

17. Fifth swimmeret—same as fourth.

18. Uropod—used in swimming backward.
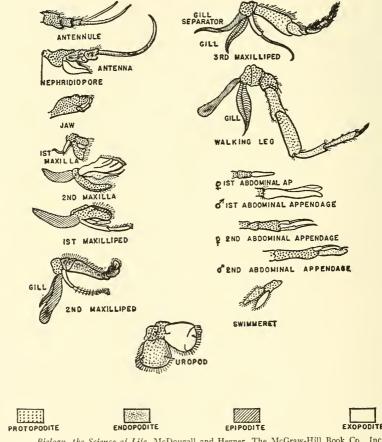
The appendages of the crayfish may be used to illustrate a very important biological principal, **homology.** Body structures which arise in similar ways in the embryo are said to be **homologous.** Thus, we can say that the appendages of the crayfish are homologous to one another even though they become greatly modified and assume different functions in the adult. This not only applies to a series of similar structures on the body of one animal, but to structures on different animals that arise in the same way embryologically. For instance, the arm of a man, the wing of a bird, the foreleg of a horse, and the pectoral fin of a fish all arise as a little outpocketing of the ectoderm and mesoderm at the same spot on each embryo. In the early embryo of each of these animals the structure would appear as a little projection without any indication as to its ultimate form and function. Therefore, we can say that these four structures are homologous to one another. These all happen to have different functions, but that need not necessarily be so. The arm of a man and the arm of a monkey are used for similar functions and are homologous also.

Another biological principle, **analogy,** bears a close relation to homology and the distinction between them should be made clear. Body structures are said to be **analogous** which have the same function, but a different embryonic background. As an example, the wing of a bird and the wing of a house fly serve the same general purpose, flying, yet the two arise in an entirely different way in the embryo. The bird wing, as described previously, bears a definite relation to the front leg of other animals, yet the wing of the fly arises as a little balloon-like puffing out of the ectoderm on the back of the insect and bears no relation to its legs. Since these two structures have no embryonic relationship, yet are used for the same purpose, they are analogous to one another.

A survey of the organ systems of the crayfish shows some of them to be quite similar to the earthworm, while others show marked differ-

ences.   They are all very efficient systems indicating the advanced development of the arthropods.

Digestive System.   The crayfish is somewhat of a scavenger, eating bits of dead animals that it may find, but also catching and eating live water animals that get within reach of its powerful pinchers.   After obtaining the food, the crayfish uses the pinchers, the maxillipeds, and the maxillae as we use a knife and fork to cut up and carry the bits of food to the mouth.   The food is crushed into finer pieces by the mandibles and passed through the short **esophagus** into the **stomach.**   The anterior, or **cardiac portion,** of the stomach is for storage and is followed

FIG. 13.15.   Some of the appendages of the crayfish dissected from the body to show their structure better.   Note how they have become modified to accomplish their particular purposes.

by a **gizzard** which is lined with teeth made of chitin that grind and pulverize the food. The food then passes out into a pair of large **digestive glands,** where digestion and absorption take place. These glands, in addition to secreting the enzymes of digestion, thus serve the same function as the small intestine in the higher vertebrates. The residue is then passed into the posterior, or **pyloric portion,** of the stomach and on into the **intestine.** There is little absorption of food from the intestine because most of it is lined with chitin through which the digested food cannot pass. The intestine, therefore, serves a similar function to the large intestine of the higher vertebrates; it is primarily for storage and transportation of the indigestible residue of the food to the **anus** for elimination.
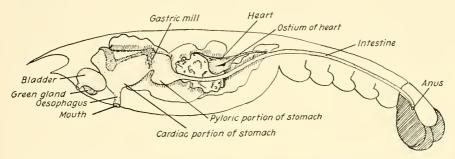
FIG. 13.6   Diagram showing the location of the organs of digestion and excretion in the crayfish. The position of the heart is also shown.

Respiratory System. The respiratory organs consist of a series of **gills** which lie in the **branchial chambers** on either side of the thoracic region of the body. The chambers are formed by an overlapping portion of the exoskeleton, the **carapace.** Water is kept flowing through the chambers by the action of the **bailer,** which is attached to the second maxilla, that is continually bailing the water out at the anterior end so that it keeps flowing in at the posterior end. This keeps the gills bathed in fresh water so that oxygen may be absorbed and the carbon dioxide given up. The process is aided by movements of the gills themselves; most of them are attached to appendages, and, when the appendages are moved on the outside, the gills are moved in the chambers.

Excretory System. A person who knows how to eat a lobster does not stop when he has finished the large muscles in the "tail." There are many of the internal organs that are good eating, but a pair of green glands at the anterior end of the cephalothorax should be avoided because they have a very bitter taste. These are also present in the lobster's first cousin, the crayfish, and are located in the ventral part of the

head region. The **green glands** are excretory organs somewhat like nephridia. Each gland consists of a ventral glandular portion which extracts the wastes of metabolism from the blood, a thin-walled bladder which stores the waste, and a short tube which empties the wastes to the outside through a small pore on the base of the antenna.

Circulatory System. Circulation in the crayfish is called the **open type** system, where blood flows through sinuses in the body, in contrast to the **closed type** system, where the blood does not leave the blood vessels in its circuit around the body. The earthworm and vertebrates have the closed type of system, whereas the fresh-water clam has a combination of both. The **heart** lies just dorsal to the anterior portion of the intestine. It connects to **arteries,** which lead from it in all directions; there are no veins. Blood is taken into the heart from the surrounding **pericardial sinus** through three pairs of openings in the heart, the **ostia.** When the heart expands, blood flows in through the ostia; when the heart contracts, valves close the ostia so that the blood cannot pass out through them, but flows out into the arteries instead. The main arteries form smaller branches which empty the blood into the body sinuses. The most important of these is the **sternal sinus,** from which the blood flows out into the gills for respiration and then flows back into the pericardial sinus to repeat the circuit of the body. The blood contains corpuscles, but is clear because there is no hemoglobin. There is an oxygen-absorbing substance in the plasma, hemocyanin, which is colorless in the body, but turns blue when removed and allowed to stand awhile.

Muscular System. The body of the crayfish is liberally supplied with muscles which move the body and its appendages. The crayfish can crawl along rather slowly in any direction, using its walking legs, but if it really gets in a hurry it darts backward for several feet so rapidly that it can hardly be seen. It is able to do this because the greater portion of the abdomen is filled with a strong **flexor muscle.** When the fan-like portion at the rear of the body is suddenly pulled forward against the water by the flexing of this muscle, the animal is jerked backward at great speed. There is a much smaller **extensor muscle** lying on top of the flexor which extends the abdomen.

Nervous System. This system is very much like that found in the annelids. The **brain** is in the dorsal part of the head region, and two **circumesophageal connectives** circle the esophagus and join ventrally to form the **nerve cord.** There are enlargements of the nerve cord, **ganglia,** in the different segments, and the sensory and motor nerves are given off from the ganglia. The ganglia in the second through the sixth segment are fused to form one large **subesophageal ganglion,** but the re-

maining thoracic ganglia and the abdominal ganglia remain distinct in each segment.

The sense organs include a pair of stalked **compound eyes** on the first body segment. The eyes are called compound because each is composed of many individual eyes; there are about 2,500 single eyes in each. Each single eye is a long, cone-shaped structure. At the outside there is a facet which serves as a lens, and internally there are light sensitive cells which receive the image. Also, there are pigmented cells within the eye. These cells contain colored granules which can move up and down in the cell. This movement regulates the amount of light which reaches the sensory cells. A similar function is performed by the iris of our eyes. It opens and closes to accommodate different intensities of light.
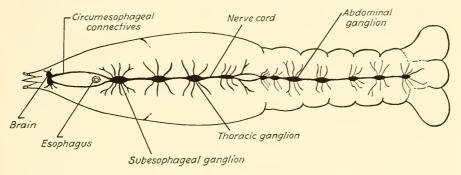
FIG. 13.7. Dorsal view of the central nervous system of the crayfish. This diagram shows the appearance of the nerve cord and the ganglia on the ventral surface of the body after the body organs have been removed.

Sense organs of **equilibrium** are found in the base of the antennules. One of these consists of a small sac which contains fine grains of sand which shift around as the crayfish changes its position. These shifting grains stimulate delicate nerve endings in the sac and the crayfish is able to adjust its position so as to maintain its equilibrium. One research worker confused the crayfish by substituting iron filings for the sand grains in these organs. When a magnet, placed above the animal, caused the iron filings to be drawn to the top of the sacs, the crayfish became disoriented and turned over on its back and remained there as long as the magnet was working.

The appendages and other parts of the body bear small sensory bristles which are of two kinds. One group is sensitive to **touch**, while another is sensitive to chemicals and might be called sense organs of **taste**.

Reproductive System.　The male reproductive organs consist of a pair of **testes** lying just under the heart and a **vas deferens** leading from each to an opening in the base of the fourth walking leg.　The sperms are removed from this opening and transferred to the female by the first two pairs of swimmerets which are modified in the male for this purpose. The female system consists of the paired **ovaries** and an **oviduct** leading from each to an opening in the base of the third walking leg.　Also, there is a **seminal receptacle** on the ventral surface of the body between the bases of the fourth and fifth walking legs.

During the breeding season, which is usually in the fall, the male will approach the female and a struggle follows with the female apparently making a great effort to resist his advances.　However, her resistance finally weakens and the male throws her over on her back.　As
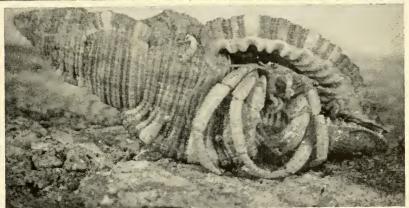
Photo by Winchester

Fig. 13.8.　Regeneration in the crayfish.　The right cheliped, which has been torn off, is in the process of regeneration.

he stands over her, sperms flow from the openings of the vasa deferentia and are guided into the seminal receptacle of the female by the first two pair of swimmerets which are modified for this specific function.　The sperms are kept here through the winter months and fertilize the eggs in the spring.　When the proper time arrives for egg-laying, the female first secretes an adhesive substance from the basal portion of the uropod. This is spread over the swimmerets.　Then the crayfish turns on her back and lays the eggs which are passed backward over the seminal receptacle to receive the sperms which were deposited there.　They are then guided back and stuck onto the swimmerets by the adhesive which covers them.　During the embryonic development of the young crayfish within the eggs, the female waves the swimmerets back and forth in the water in order to keep the embryos well supplied with oxygen.　Upon hatching, several months later, the young crayfish cling to the swimmerets of the mother until after their second molt.

Photos by Winchester

FIG. 13.9.   Crabs.   Fiddler crabs above and hermit crab below.

Regeneration in the crayfish is limited to the appendages and eyes. If a part of an appendage is injured, the entire appendage will most likely be cast off at a certain joint and replaced by regeneration.   This is known as **autotomy**.   It prevents excessive bleeding from crushed and mutilated portions of the appendage, for little bleeding will occur from a break at a joint.   There are special muscles at the joint which contract and not only break off the appendage, but also close the open blood spaces.

Among the other crustaceans, the **lobster** is probably the most important economically because it is a source of delicious food.   It is just

an enlarged salt-water edition of the crayfish, and the body organs and habits are very similar in the two.

The **crabs** are also crustaceans and have appendages of the cephalothorax very much like the crayfish, but the abdomen is greatly reduced and folded up under the cephalothorax. There are many varieties of crabs. The edible or **blue crab** is an important source of food in the United States. Unlike the lobster, the main muscles consumed as food are located in the cephalothorax and are used to control the powerful pinchers. The **fiddler crab** has one pincher larger than the other in the males and the two are held in a position somewhat like a bow and "fiddle." The **hermit crab** backs up inside a deserted mollusk shell, usually of the coiled gastropod type, and carries it around on his back. The body is soft and can curve around inside the shell. The little **sand crabs** come out on the sand of the beach and can run very fast over loose sand, traveling sideways for better traction. They are so common on some beaches that a sun bather stretching out on the sand must be careful or he might receive a pinch which informs him of the sand crab beneath him.
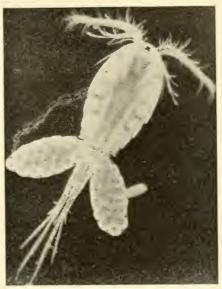
Shrimp cocktails as a dinner appetizer have become standard fare in all parts of the United States. The catching and shipping of these **shrimp** constitute a major industry in certain coastal regions, especially in southern Louisiana. The industry in this region was stimulated recently when very large shrimp were discovered in the Gulf of Mexico. It seems that the shrimp that we ordinarily eat are not fully grown, but they mature sexually and reproduce in this small size and then retire into the Gulf and congregate in large schools. Here they grow nine and ten inches long.

The **fairy shrimp** are very beautiful little crustaceans often found in great numbers in small temporary ponds in the spring. They swim on their backs by undulating movements of the appendages, making a beautiful sight. They possibly get their name from the fact that they seem to have the power to make themselves disappear in the summer when the ponds dry up and reappear in the following spring. The adults actually die when the ponds dry in the spring, but the previously laid eggs live through the dry summer and are ready to hatch when the rains and warmth of spring return.

Barnacles are crustaceans that bear a superficial resemblance to mollusks. They have developed a shell and become permanently attached to some solid support as adults. The young are free-swimming, but soon pick a rock, wharf, ship bottom or similar underwater structure for attachment. They are a great nuisance to shipping since ships often have to be hauled into drydock to have the barnacles scraped from them.

Courtesy General Biological Supply House

Courtesy General Biological Supply House

Courtesy General Biological Supply House

Photo by Winchester

FIG. 13.10. Small crustacea. Upper left: fairy shrimp. Upper right: cyclops. Lower left: water flea, Daphnia. Lower right: pill bugs.

Otherwise the accumulation of barnacles greatly reduces the speed of the ships.

Water fleas are aquatic vertebrates which are only about one tenth of an inch long, and since they do not bite, they appear to have little economic importance. They breed very prolifically, however, and furnish an important source of food for many animals including important

game and food fish. In size and general body shape they resemble fleas (insects), but their body structure is entirely different.

Cyclops was a huge giant with a single eye in the center of his forehead according to Greek mythology, but according to a zoology textbook the cyclops is just another small crustacean about the size of the water flea. It certainly does not resemble the mythical Cyclops in size, but it does have a single eye in the center of the head region.

The **pill bug,** or sow bug, is another crustacean. It differs from the others studied in that it spends its life on the land. Like all crustaceans, however, it breathes by gills, but is able to exist on the land by coming out only when the air is very moist, which is usually at night. During the day it gets under rocks, logs, or similar structures where the humidity is high and the air cool. Its name is derived from the habit of rolling into a tight little ball when disturbed which makes it appear somewhat like a little pill. Sometimes pill bugs are quite destructive to garden plants and poison must be put out to kill them.

Classification and Derivation of Words

Phylum Arthropoda (Gr. *arthron,* joint; *pous,* foot; refers to the jointed condition of the appendages).

    Class Crustacea (L. *crusta,* crust-like covering; refers to the crust-like exoskeleton).

        Genus Cambarus (Gr. *kammaros,* crayfish).

        Other examples: lobsters, crabs, shrimp, barnacles, water fleas, cyclops, and pill bugs.

REVIEW QUESTIONS

1. List the points that indicate that the arthropods are a very successful group of animals.
2. Give the characteristics of the Arthropoda.
3. What are the advantages and disadvantages of the endoskeleton as compared to the exoskeleton?
4. What is a biramous type of appendage? Name the parts of a typical biramous appendage.
5. What is the meaning of the terms homologous and analogous?
6. Describe the entire digestive process in the crayfish.
7. Compare the open with the closed type of circulatory system.
8. Can you think of a good reason why the flexor muscle of the crayfish is so much larger than the extensor muscle?
9. Explain how the sense organ of equilibrium functions in the crayfish.
10. Compare the function of the swimmerets in the male and female crayfish.
11. How do the fairy shrimp pass through the dry summer months?
12. What is the economic importance of barnacles?
13. The pill bug lives on land yet it uses gills for respiration. Explain.

14.   What characteristic gives cyclops its name?

15.   How does the hermit crab secure protection from its enemies?

16.   What is the importance of autotomy in crustaceans?

17.   Compare regeneration of the crayfish with that of some of the other animals we have studied.

18.   Describe a compound eye.

19.   How are water fleas economically important?

20.   When a female crayfish has eggs on her swimmerets she will wave them back and forth continuously.   What is accomplished by this action?

14

Arachnids, Centipedes, and Millipedes —Arthropods (Cont.)

Class—Arachnoidea

This class includes such animals as spiders, scorpions, mites, and ticks. There is probably no class in the entire animal kingdom that includes such an array of animals that are more repulsive to so many people than this one. A large part of this aversion is unjustified, for many of these animals are our friends, but you would probably not change a person's opinion by telling him that he, or more probably she, should love spiders because they destroy so many harmful insects.

The list of arachnids seems to include a motley group of animals with little in common, but a survey shows that they have a number of like characteristics which causes them to be placed in the same class. There are two main body parts, the **cephalothorax** and **abdomen,** and **four pairs of walking legs** which are on the cephalothorax. There are no compound eyes and no chewing jaws.

Spiders are the best known of the arachnids because many of them spin conspicuous webs which give evidence of their presence. The cephalothorax bears a number of **simple eyes** on the anterior dorsal surface. These are not well-developed eyes and it is doubtful if the spiders can see more than five inches. They have a pair of **fangs** at the anterior end of the ventral surface of the cephalothorax which are connected internally with poison sacs. The fangs are like hypodermic needles; and, when a spider bites, a little poison is forced out of the poison sacs and through the fangs into the wound. Just back of the fangs is a pair of appendages, the **pedipalps,** which look like a miniature pair of legs. These are mostly sensory in function, but also serve as a copulatory organ in the male and help to squeeze the "juice" out of an insect in feeding. The abdomen is unsegmented and bears three pairs of **spinnerets** on the ventral surface. These are sometimes mistaken for stingers, but no spiders can sting and these organs are used only for spinning the web. Spiders breathe by a pair of **book lungs** in the anterior portion of the abdomen and also have trachea like the insects. Each lung consists of a single sac with an external opening, through which air is

taken in, and fifteen or twenty folds within, which resemble the leaves of a book. Gaseous exchange takes place as the air circulates over these leaves.

The web plays a vital part in the life of the spider and its many uses make an interesting study. Inside the abdomen there are several silk glands that secrete a viscid fluid from which the web is formed. This liquid is forced out of the spinnerets under rather high pressure and hardens almost instantly on contact with the air to form the web. This is the same principle which we use to produce rayon and nylon thread, forcing a viscid liquid through tiny holes to harden in the air, but the spiders had been using the method long before man thought of it. One of the best known uses of the web is as a trap for insects which provide most of the food for spiders. To the inquisitive mind of a child, one of the great mysteries of nature is how the spider keeps from getting caught in its own web. The spider can walk around over the web, yet an insect becomes entangled immediately on contact. At least a partial answer can be found in the types of silk glands; there are some that spin a web that is sticky and others that spin a web that is not. The spider seems to mix the strands in forming the trap and knows which to walk on, but the hapless insect does not. The funnel-shaped and the orb-shaped webs are the most popular types of traps used by the spiders. There is no sight more beautiful than the geometrical pattern of the orb weaver's web sparkling with dew drops in the early morning sun.

When an insect contacts the web the spider goes into action. It rushes out and begins squirting sticky web at its struggling prey. The more the insect struggles the faster it is entangled in this stream of web and is soon helplessly awaiting its doom. The spider may hang it by a thread and spin it around while emitting web on it so that it is soon trussed up like a mummy and can be hung up for future use, just as we would hang a smoked ham in the pantry. On the other hand, if the spider is hungry it will eat the insect on the spot. Since spiders do not have jaws, the insect cannot be chewed up and swallowed; but the spider will bite a hole in it and inject digestive enzymes, and suck up the liquified digesting food. The empty exoskeleton is then cast aside and an accumulation of these skeletons can usually be found below a web as a testimony of the effectiveness of the trap.

Some spiders, such as the wolf spider, do not use the web as a trap, but stalk and pounce on their prey like a tiger. However, these may spin web to line their nests, which are usually holes in the ground, so that they are soft, dry, and cozy.

The web may be used as a convenient means of transportation for the spiders. A spider on the ceiling can lower itself to the floor by stick-

ing the web to the ceiling and spinning web out as it comes down. It can also wind this web in and go back up. It can move from one tree top to another by spinning a little tuft of sticky web and throwing it out in the breeze while spinning a single strand attached to it like a boy flying a kite. When the tuft hits a solid object and sticks, the spider has a cable on which to cross. This accounts for the many single strands of web which a person contacts, usually across the face, on a walk through the woods.

Courtesy General Biological Supply House

Fig. 14.1. Trade-mark of the black widow. The red or orange mark in the shape of an hourglass on the ventral surface of the abdomen of the female black widow is a reliable means of identification of this, our most dangerous spider.

Although a housewife that has to clean cobwebs from the ceilings may not think so, spider web is of value to man as well as to the spider. It is an ideal type of thread to place in optical instruments to form what are called "cross hairs." These enable a person using a gun sight or similar instrument to center the target. Two strands of web are placed in the instrument so that they cross at right angles in the exact center. Spider web is ideal because it is very slender, yet possesses strength greater than steel; a steel thread the same diameter as a strand of spider

web would not bear as great a weight as the spider web. Spider web is impervious to variations in temperature and humidity and, therefore, is not altered in its position by extremes in climate. The collection of this web for commercial use is quite simple. A spider, frequently the black widow, is held on the end of a stick and pushed off with another stick. As it is pushed off it fastens a web to the first stick and lowers itself gently to the floor, spinning web as it goes down. This single strand is clipped loose and the spider is picked up on the stick and the process repeated over and over again.

The bad reputation which the spiders have among the general public can be traced to the fact that they have fangs and poison, and some of them can give a rather painful bite. They are not particularly vicious, however, and bite only in self-defense. There is only one in the United States that can cause serious symptoms in man, the black widow. This is not a large spider, but has poison sacs that extend far down into the body and thus can inject a rather large amount of poison. This, coupled with the fact that the poison is of high potency, accounts for its serious effects on the human body. Bites are comparatively rare, considering the wide distribution and abundance of this spider, because the black widow is rather shy and retiring. However, a female protecting an egg case will bite rather readily when disturbed, and most bites are received in this way. The poison is of a neurotoxic type, nerve poison, and causes severe systemic reaction for several days after the bite. Some of the symptoms are pain in the muscles, difficulty in breathing, nausea, mental confusion, and general retardation of the body functions. While the symptoms are very serious and not to be minimized, the bite is fatal in only rare instances and then only in unusual circumstances.

Reproduction among the spiders is very interesting, and a study of this process among the black widows may serve as a typical method for the group. Spiders are ordinarily solitary animals; that is, they do not live in social groups. There is a good reason for this lack of sociability; spiders are cannibalistic and often prey on one another when they are confined to close quarters. During reproduction, however, there must be some association and the cannibalistic tendencies are repressed temporarily at this time. A female ready for reproduction will get in the center of her web and wait for a male. Some studies show that she casts out single strands of web which are carried a considerable distance by the wind. When a male contacts one of these strands he picks up some sort of telegraphic signal which indicates that the female is ready for insemination. He can follow the strand of web and it will lead him to her. The male is much smaller than the female and he approaches her with great caution. He will come in slowly and then turn

and run away only to return and repeat the process over and over again, each time getting a little nearer to the female.   In preparation for this occasion the male has already removed a ball of sperms from his reproductive organs and is carrying it in his pedipalps.   After repeated approaches in which the female does not attempt to capture him, the male finally approaches close enough to tuck the ball of sperms into her seminal receptacle.   Then, again he turns and rushes away, but this time the female is likely to pursue him and may overtake him and eat him.   This is where the black widow gets her name—she is black and
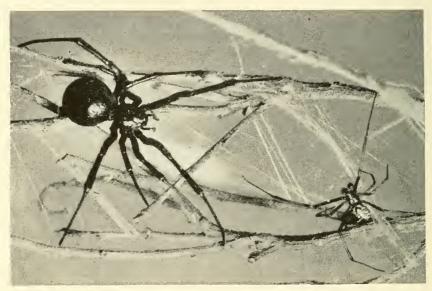
Photo by Lee Passmore

FIG. 14.2.   Female and male black widow spiders.   It is easy to understand why the male runs from his larger, cannibalistic mate after insemination is accomplished.

may become a self-made "widow" by this action.   Later she will lay the eggs and spin a web around them to form an egg case.   She will defend this viciously against any intruders.

The little spiders hatch within the case and soon break out and climb on their mother's back.   Female spiders are frequently seen with their backs covered with tiny spiders clinging onto the hairs.   In some species, they are known to eat their mother before scattering out to shift for themselves.   Distribution among spiders is an important thing, for if a hundred or more all set up housekeeping in the same vicinity there would be serious competition for food.   Here, again, the web comes in handy.   The little spiders climb the nearest tree or other elevation and

each spins a little tuft of web which it throws out into the breeze like a parachute. In this way it is carried a considerable distance.

Tarantulas are often thought of as being very poisonous, but experiences with their bites indicate that they are painful, but not dangerous like the black widows. They are quite large and hairy and are jumping spiders that pounce on their prey which they find in their nocturnal wanderings.
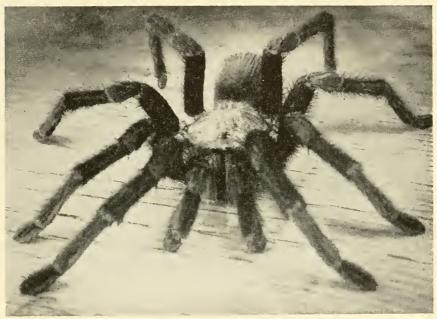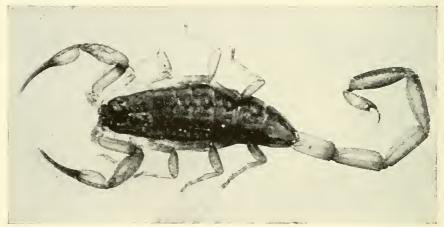
Photo by Winchester

Fig. 14.3. A tarantula, largest of the spiders. The tarantula does not spin a web, but stalks its prey and pounces on it like a tiger. Their large size and hairy body, together with their quick jumping habit, make them greatly feared by many people, but their bite is not serious.

A **scorpion** bears a formidable sting on the tip of its long curved "tail" which makes it highly respected by anyone who has been stung by one. Stings may occur frequently when scorpions are around the house because they come out at night in search of food and secrete themselves in some secluded place in the daytime. The author has found that this is likely to be the inside of a man's trousers and they make their presence suddenly and painfully known when the trousers are put on. In the tropics where they may be very abundant, a person is foolish to put on a shoe without first shaking it out to remove a scorpion that might

very likely be in it. Scorpions are rather plentiful in the southern United States.

Courtship among the scorpions is interesting as in the spiders. Before mating they will grab claws with one another and do a dance which is called the "dance à deux." Holding claws is probably not so much a sign of affection as it is of suspicion of the partner, since the scorpions are cannibalistic. The eggs are retained in the body of the female until hatching and the young scorpions are brought forth alive. These clamber on their mother's back to ride around awhile, and some varieties are known to eat the mother as their first square meal.

Photos by Winchester

FIG. 14.4. A scorpion. This arachnid is well respected because of the powerful sting on the tip of its long, curved abdomen. The sting is extremely painful, but not dangerous.
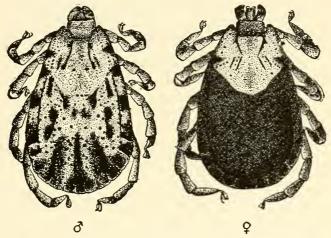
The **granddaddy longlegs** look somewhat like the spiders, but have extremely long legs and segmented abdomens. Their long legs seem to be a disadvantage, since they move rather awkwardly and readily pull off a leg if it is grasped. They are often called harvestmen because they are so abundant at harvest time.

The **mites** deserve their name because they are so tiny, but they cause trouble all out of proportion to their small size. The **itch mites** burrow into the skin and the females lay eggs as they go. When these eggs hatch and the young mites begin burrowing in all directions a person has the "itch." The mites are too small to be seen with the naked eye, but, if scrapings are taken from the infected skin and placed under the microscope, small arachnids will be seen. The term "seven year itch," which is often given to this infection, indicates that it is not easy to cure, but

sulfur soap and ointments will usually terminate the infection in a short time.

The mange of cats and dogs and other domestic animals is caused by the **mange mites** which burrow around in the skin like the itch mites.

The tiny **chiggers** or red bugs are mites that may be so abundant in the southern part of the country that a person will look as if he has the measles after walking through grass in the spring or early summer. They attach themselves to the skin and inject a digestive fluid which forms a little burrow through which they feed. This fluid is quite irritating to the skin of some persons and causes large, raised red blotches

♂   ♀

Introduction to Parasitology, Chandler, John Wiley & Sons, Inc.
Fig. 14.5.   Spotted fever tick.

and an almost unbearable itching. Chandler quotes a descripiton of them which cannot be improved upon. The chigger is a "small thing, but mighty; a torturer—a murderer of sleep; the tormenter of entomologists, botanists, and others who encroach on its domains; not that it bites or stings—it does neither; worse than either, it just tickles."

Plants are by no means exempt from mite infestation. One of the most serious of the plant mites is the **red spider.** Red spiders are great pests on fruit trees, and evergreens may be killed by a heavy infection of them. Protection may be given by regular use of poisonous sprays that kill the mites.

The **ticks** are blood-sucking arachnids that not only cause inconvenience to their hosts, but spread serious diseases. This is possible because their life history involves several hosts. When the young ticks

first hatch they will climb on the nearest bush and begin a vigil that ends either in starvation or a full meal from some passing animal. With the slightest rustle of the leaves of surrounding bushes, which might indicate the approach of a possible host, the little tick becomes very excited and waves its legs frantically in the air. If a suitable host gets close

Photo by Winchester

Fig. 14.6.   The king or horseshoe crab. This animal is not a true crab, but an arachnid, related to the spiders.

enough the tick grasps it and crawls around on its skin for awhile, selects a suitable place, pierces the skin and begins sucking. It buries its head in the wound and holds so tightly that it may be pulled in two without releasing its hold. However, it is said that a tick will release its hold rather quickly if touched with the lighted end of a cigarette. After engorging itself for several days the young tick will drop off on the ground,
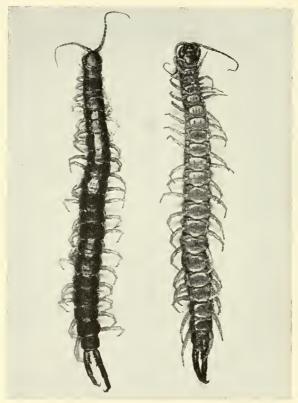
rest for a week or so, molt, and climb another bush and again take up its patient vigil. This may be repeated several times during the life of the tick and germs ingested along with the blood of one host may be transferred to a later host. Texas cattle fever is a serious disease that infects cattle, and expensive dipping of cattle for tick eradication is a necessity in many of the cattle-raising regions of the country. Spotted fever is a serious human disease which people may develop from bites by ticks that have previously fed on infected rodents. Tularemia is another disease which people may take from ticks that have fed on infected animals.

The **king crab** or horseshoe crab is a salt water animal that is found along the Atlantic Coast from Maine to Yucatan, Mexico. It is sometimes classed as an arachnid, but some authorities prefer to put it in a separate class of its own. It bears a superficial resemblance to some of the true crabs. Instead of book lungs, as in the spiders, the king crab has book gills which are in full view on the underside of the abdomen and obtain oxygen from water rather than air. King crabs are mild, inoffensive creatures with small, weak claws. They feed on almost any sort of small animal which they can overpower. Their larvae are very primitive and are known as trilobite larvae because they closely resemble an extinct group, the *Trilobita*. Because of this resemblance it is generally believed that king crabs are descended from these fossil creatures.

Class—Chilopoda

The name centipede means "hundred legs," but the number of legs in these animals may vary from 30 to more than 400 in different species. The body of a centipede consists of loosely jointed segments with a pair of legs on each segment except the first and the last. The first segment bears a pair of vicious-looking fangs that are connected with poison sacs and can inflict a painful bite. There is a widespread superstition that a person's flesh will rot and fall off if a centipede runs across it, and another that a centipede can inject poison from its legs. Both are without foundation in fact. The author has seen centipedes in the Southwest measuring up to eight inches long, and tropical forms are known which are up to a foot in length. Most of those in the United States, however, are much smaller and are beneficial because of the large number of insects which they eat. The house centipede is a species with rather long legs that may often be seen in human dwellings. Like other centipedes they come out at night in search of food, and their presence is often unknown until they may be discovered in

the bathtub some morning where they ventured and were unable to climb the slick sides to get out. They seem to make no attempt to bite people and they destroy many household insect pests. For this reason they are beneficial and many people will not destroy them when they are found.

Courtesy Southwestern Biological Supply Co.

Fig. 14.7.   Centipede.   Dorsal and ventral views.

Class—Diplopoda

The millipedes or thousand-legged worms have so many legs that it would seem very difficult to move them all in a coordinated manner, but they manage very nicely. Like the centipedes, the body is divided into segments, but there are two pairs of legs per segment rather than one. Since one pair of appendages is the usual maximum among the arthropods, this condition would be hard to explain but for a study of

the embryonic development. Developing millipedes have only one pair of legs per segment, but later the segments fuse in pairs so that the adults show only one segment for two pairs of legs. Millipedes have no fangs and are entirely harmless.

Classification and Derivation of Scientific Words

Phylum Arthropoda (Cont.)

Class B. Arachnoidea. (Gr. *arachne,* spider). Spiders, scorpions, granddaddy longlegs, mites, ticks, and king crabs.

Class C. Chilopoda (Gr. *chele,* claw; *pous,* foot). Centipedes.

Class D. Diplopoda (Gr. *diploos,* double; *pous,* foot). Millipedes.

REVIEW QUESTIONS

1. Describe respiration in the spiders.
2. Discuss the uses of spider web by the spiders.
3. Discuss the uses of spider web by man.
4. Describe reproduction in a typical spider.
5. How are young spiders distributed?
6. How do scorpions differ from spiders in their method of injecting poison?
7. Describe the activities of the itch and mange mites.
8. Explain how germs may be transferred from one animal to another by ticks.
9. What are the primary distinctions between the centipede and the millipede?
10. Explain how it is that millepedes have two pairs of legs on each body segment, whereas arthropods generally have only one pair.
11. Why is the house centipede of economic value?
12. What are red spiders and how do they harm man?
13. Why is it thought that king crabs are closely related to the extinct Trilobita?
14. How do chiggers obtain their food?
15. Which is our most poisonous spider? How does its bite affect the human body?
16. Describe the two primary methods which spiders use to capture their food.
17. How does a spider, without chewing mouth parts, obtain food through the thick shell of an insect?

15

The Insects—Arthropods (Cont.)

One of the main reasons for the great importance of the arthropods is the inclusion of the insects in the phylum. A person may feel belittled when called an insect, but, after a study of this interesting group of animals, he may feel complimented, for insects are certainly a very successful class of animals. They make up only one of about fifty animal classes, yet there are more species in this one class than there are in the other forty-nine. They are abundant almost everywhere on the face of the earth; there are probably more of them in your back yard than there are people in your city. They have a persistence and aggressiveness that are unequaled in any other animals. Consider a mosquito humming around your head; no amount of slapping or waving discourages it; it will persist for hours if necessary until either a full meal or death rewards it efforts. Insects have an ingenuity that challenges the best that man has to offer. They were making paper from wood pulp when man was chiseling crude characters on stone tablets. Domesticated animals and cultivated plants were their source of food supply long before man had the idea. They have a highly developed social organization that functions more smoothly than the best that modern man has devised. They have a strength all out of proportion to their small size; an ant commonly carries loads several times its own size and weight; a flea easily jumps a hundred times its own body length. The list of insect accomplishments could be greatly extended; they are certainly not a group to be belittled in spite of their small size.

Insects, as a group, are one of man's greatest enemies. They destroy our food plants. It is very hard to find a peach or an apple without a "worm" in it unless the tree was carefully sprayed during the time the fruit was developing. Few ears of fresh corn can be bought at the market without one or two "worms" that have eaten some of the tender kernels at the end, or signs of their previous presence. Grasshoppers destroy and damage crops of all kinds. Hessian flies claim a large part of the wheat crop each year. Even after a crop is harvested it is by no means exempt from insect damage; large quantities of stored grain, fruit, and other foods are destroyed each year while awaiting consumption. Insects are a general nuisance with their bites and stings, and the most

serious germ diseases of man are spread by insects. Our clothing is destroyed by insects; furs, woolens, mohair, and feathers furnish good eating for the larvae of the clothes moth. Some do not wait for material to be made into clothing before destroying it; the cotton boll weevil may take as much as a fourth of the entire potential cotton crop each year. Books and valuable papers are injured and destroyed by the silverfish,
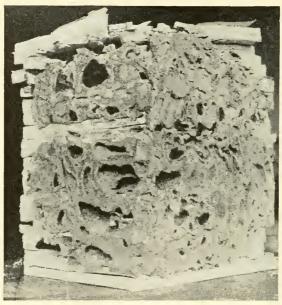
FIG. 15.1. The corn ear "worm" does great damage to the corn crop by eating the kernels. It is the larval form of a moth, *Heliothis armigera*.

or fishmoth; termites destroy all types of wooden construction and may enter and destroy books and other stored paper products.

When we constantly have to battle insects to hold such destruction in check and spend millions of dollars each year in attempts to control them, we may wish that there were no such things as insects on the earth. Yet, insects are of such great economic value that if they were completely eradicated we would find this a very different world in which to live. Most of our fruits, many vegetables, and many of our grains would disappear with them. There would be no cotton or silk; most of the land birds and most of the fresh-water fishes would die of starvation. Many

peoples of the world would be without a direct source of food. Fried ants and grasshoppers are widely eaten in India; fried caterpillars are sold like hot dogs on the streets of some cities in Mexico; certain African natives eat the large tropical termites with great relish. We could probably continue to live without insects, but our lives would be greatly affected.

FIG. 15.2. Termite damage to books. In the tropics termites often come out of the walls and eat their way into books. This stack of books has been completely ruined by such action.

Insect Characteristics

Insects have three distinct body parts, the **head, thorax,** and **abdomen.** Embryonic or larval insects resemble annelids in that there are numerous body segments which are similar to one another. Larval forms are often called worms because of this resemblance; a caterpillar or a maggot looks more like a worm than an adult insect. However, during a typical insect development the anterior four segments fuse to form the head, the next three form the thorax, and the remainder of the segments form the abdomen. The dividing lines between the segments cannot be seen in the head, are visible as indentations in the chitin sur-

rounding the thorax, and remain distinct with independent movement in the abdomen.

Insects have **three pairs of legs.** This is the most distinctive characteristic of the insects because no other group of animals has six legs and all of this group have this number. There is one pair attached to the ventral surface of each segment of the thorax.
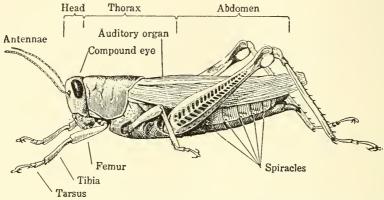
FIG. 15.3. A tomato worm parasitized by the bracoid flies. Some insects are highly beneficial through destruction of other insects that are harmful. This tomato worm will never complete its metamorphosis into a sphinx moth. A bracoid fly has laid its eggs in the caterpillar and the young have now formed cocoons.

Insects usually have **two pairs of wings,** one pair attached to each of the two posterior segments of the thorax. There are a few, however, that have no wings at all and others with only one pair, so this is not a universal characteristic of the group.
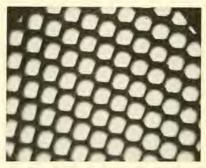
Insects **breathe by spiracles.** These are tiny breathing pores found on the side of the abdomen, one pair on each segment, and usually two additional pairs on the posterior thoracic segments. These connect internally with tiny tubes, trachea, which carry the air directly to the parts

of the body where needed. These distribute the oxygen much more readily than can be done with lung or gill respiration and give insects the tireless energy which enables them to accomplish so much in spite of their small size. However, this method of respiration makes them very

Foundations of Biology, Woodruff, The Macmillan Company

Fig. 15.4. Side view of a grasshopper. The typical characteristics of an insect are shown in this drawing.

susceptible to foreign substances in the air for they are quickly distributed over the body. We take advantage of this by spreading insecticides in the form of sprays or dusts. A beekeeper can make a hive of bees quite docile by blowing a few puffs of smoke in at the top of the hive. Chickens can often be seen "delousing" themselves by sitting in a nest of fine dust and working it through their feathers so that the lice are killed by a clogging of their spiracles by the fine dust particles.

Courtesy General Biological Supply House

Fig. 15.5. Portion of the eye of the horsefly. The typical arrangement of facets that compose a compound eye is shown in this photograph.
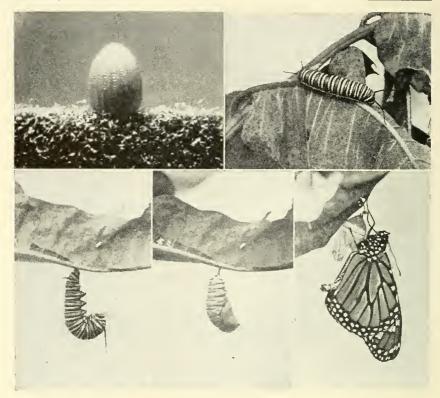
Insects have **compound eyes.** All but a very few primitive insects have this method of vision, which was described in the discussion of the crayfish. Some species have larger compound eyes, with a correspondingly greater number of individual facets than others, and accuracy of vision seems to depend on the number of facets. Since the eyes tend to curve around the head, there are some facets pointing in almost every direction so that it is quite difficult to approach an insect without being seen by some of these structures. About the only way a person could approach a fly without being seen is from below and to the rear and it would be a little difficult to get in that position.

Insect Metamorphosis

Through observation of larger animals we think it natural that the newly born or newly hatched offspring should rather closely resemble their parents, except for size, and that they should gradually grow into adult size. This is by no means true among insects, however; many larval insects would be classed in a different phylum if their life history were not known. There is no marvel of nature more astounding than the transformation of a green worm-like caterpillar into a beautiful butterfly.

Insect metamorphosis may broadly be divided into three major types. The first that we will consider is **complete metamorphosis.** Life starts with the **egg** which hatches into a **larva,** this being usually worm-like in nature. Common names of larvae indicate their similarity to worms— bag worms, grub worms, silk worms, measuring worms, and fuzzy worms are all insect larvae. Insect larvae have a voracious appetite and eat nearly all the time. They are usually able to do this because their mothers have laid the eggs near a plentiful supply of food. Because of their rather gluttonous feeding habits they grow rapidly; a fly maggot will double its size in a few hours and increase its size several hundred times in a few days. A single tomato worm may eat half of a large tomato in a day and increase its size accordingly.

Finally, the larva seems to have eaten its fill and goes into a quiescent stage called the **pupa.** It may spin threads of silk around itself to form a cocoon in which it spends its pupal state, or its outer body covering may simply harden to form a pupa case. The metamorphosis into the adult condition takes place within this covering and a fully developed **adult** emerges as the fourth and final stage in the development of an insect with complete metamorphosis. The adult is as large as it will ever be when it emerges; big flies do not grow from little flies; they are
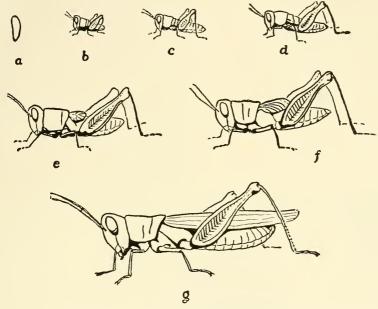
Fig. 15.6. Complete metamorphosis, illustrated by the monarch butterfly. The highly magnified egg is shown at the upper left. This hatches into a worm-like larva that feeds extensively. In the upper right the larva prepares to form the pupa. The quiescent pupa is shown in the lower center and the adult butterfly emerging from the pupa case at the lower right.

big or little flies when they leave the pupa case and retain their size throughout their lives. This is because of the confining exoskeleton.

The second method of insect development is called **gradual metamorphosis.** In this method, which may be illustrated by the grasshopper, the **egg** hatches into something that resembles the adult, but must undergo a series of gradual changes before it becomes the adult type. The immature stages of such metamorphosis are called **nymphs.** A newly hatched grasshopper nymph can be recognized as a grasshopper; it feeds in the same way as the adult and lives in the same type of environment, but its body proportions are somewhat different. It has no wings, its body is proportionately shorter, and the hind legs are not as well adapted to jumping as in the adult. It increases its size and be-

comes like the adult through a **series of molts.** When a nymph is ready to molt, a fluid will form between the body and the skeleton to separate the two and the skeleton splits down the back to let the insect emerge. It has a soft body covering at this time and swallows air to stretch it while it is hardening. When the new skeleton hardens, which may be within an hour, the insect may be twice its original size and it seems impossible that it could have come from its cast-off exoskeleton. The grasshopper has five molts, but other insects with gradual metamorpho-
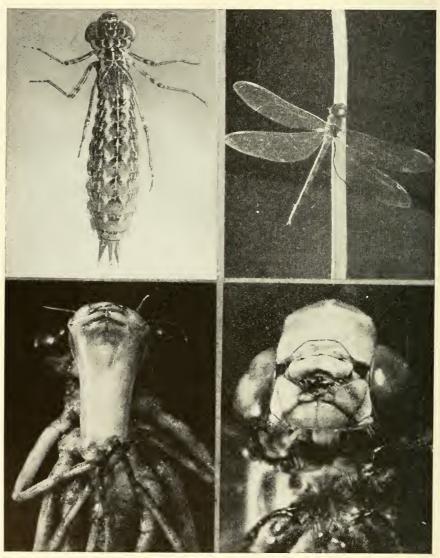
FIG. 15.7. Gradual metamorphosis of the grasshopper.

sis may have as many as twelve. The **adult** emerges at the final molting.

The third method of insect development is called **incomplete metamorphosis.** This is similar to the gradual metamorphosis in that the adult is produced after a series of molts of immature stages. The primary difference is that the immature insects with incomplete metamorphosis live in entirely different condition from their parents and feed in a different manner, with special body parts not possessed by the adult. The immature stages all live in the water and are called **naiads.** The dragonfly might be mentioned as an example of this type of metamorphosis. The adult flies in the air, catching other insects for food.

The **eggs** are laid in the water and hatch into naiads that somewhat roughly resemble the adult, but have a very long pair of jaws which they use to catch small water animals for food. Thus, the method of feeding

Fig. 15.8. Incomplete metamorphosis. The naiad of the dragonfly undergoes a series of molts as it increases its size and becomes more like the adult. However, it lives in the water and feeds in an entirely different manner. The lower photographs show the mouth parts of the naiad and the adult to emphasize this distinction.

is quite different from the adults. Respiration must also be different; the adult breathes air by means of its spiracles, but the naiads suck water in and out of their anus in order to absorb the needed oxygen. When ready for its final molt the naiad will crawl up out of the water and emerge with fully formed wings ready to take up its life in the air.

Finally, there are a few primitive insects that have **no metamorphosis.** In these the **egg** hatches directly into a form very much like the adult and merely increases in size without much change in body form. The silverfish and some of the lice are examples of this method.

Insect Wings

The wings of insects show great variation, and wing structure is frequently used as a basis for subdividing the class into orders. Some insects, such as fleas and fishmoths, have no wings at all. Others, such as the flies, have only one pair, but the second pair is represented by a rudimentary projection at the place where the second pair should be. Some, such as the ants, have generations without any wings at all, but eventually produce a winged sexual generation that flies out of the nest and spreads the species. The majority, however, have two pairs of wings as adults.

Wings which are used for flying are thin and light with delicate veins running through them. These are called **membranous** wings. In some insects, such as beetles, the front pair of wings has been greatly thickened and hardened to form **horny** wings. These are used for wing covers to protect the delicate second pair of wings which are membranous and used in flying. During flight the horny front pair of wings are held out to the side like the wings of an airplane. In other insects, such as the grasshopper, the front pair of wings become tough yet flexible and are called **leather-like** wings. They also act as wing covers and are held rigid in flying. Some insects, like the butterflies, have membranous wings covered with scales which rub off like a fine powder when they are handled. Some, such as the bugs, have a leather-like front part of a wing and a membranous hind part. With so many variations it is often possible to tell the order of an insect by glancing at its wings.

Insect Food and Feeding Habits

Insects are adapted to feed on almost every conceivable kind of **organic** matter. A small pile of manure dropped from the body of a cow, after the cow has extracted all possible nourishment from it, provides all the food necessary for hundreds of maggots to live and grow into flies.

An inch of rain water standing in a tin can may contain organic matter that furnishes all the nourishment needed for dozens of mosquito wigglers to live and grow. Even solid dried wood, dry feathers, paper, and starched clothing contain sufficient food for some insects to live on for their entire life or a large part of it. There seems to be almost nothing that has an organic origin that they have overlooked.

Some insects are **restricted** in their feeding habits and can eat only one or a small group of foods. Termites eat only wood; silk worms stick to mulberry leaves; the cotton boll weevil restricts itself to the cotton square or boll; fleas must have the blood of a mammal; certain wasp larvae live only on spiders. Others are **generalized** and can have a varied diet. The house fly is certainly not particular about what it eats; it may have the equivalent of soup from the body of a dead dog, an entree from fried chicken on your dining table, and finish its meal with desert from a pile of manure. The grasshoppers certainly do not restrict themselves to grass as any farmer has learned from experience with the damage which they may do to almost any kind of crop.

The **mouth parts** of insects are highly specialized to accommodate the kind of food eaten and the method of obtaining it. In general, there are two types—**biting** and **sucking** mouth parts. Those with biting mouth parts have hard chitinous jaws which work from side to side to bite off and crush the food as it is taken into the mouth. In the other group the mouth parts are fused to form a proboscis through which liquid food may be drawn. This is often sharp on the end so that it may be thrust through the skin of animals to suck blood, or through the epidermis of leaves to suck the plant sap. In attempting to control insect pests of plants it is important to know the kind of mouth parts which the insects possess. A poisonous spray put on the leaves will kill those with biting mouth parts, since they will eat the poison along with the leaves. However, those with sucking mouth parts would not be affected, since they stick their proboscis right through the poison and suck the unpoisoned sap beneath. A contact spray that will reach the bodies of these insects then becomes necessary for their control.

Insect Protection

All animals have enemies, and in order to survive as a group they must develop means of protection against these enemies. They may have **protective coverings** of the body that act as a discouragement to predators. The hard exoskeleton of most adult insects is quite effective and many soft bodied larvae, such as caterpillars, have developed prickly hairs that will pierce the mouth of any bird that attempts to eat them.

Some even have poison on the hairs and can give quite a sting to a person who handles them. Spittle bugs suck plant juice and expel part of it from the posterior end of the body and beat it into a froth with which they cover the entire body for protection.

Some insects depend on **protection by locomotion.** By rapid flight and maneuverability they escape doom from a more sluggish enemy. Some prefer to jump or run.

Courtesy General Biological Supply House

FIG. 15.9. Protective mimicry. The white arrows point to a caterpillar on a maple twig. Note the almost perfect mimicry that acts as a valuable protection from birds and other enemies.

Other insects hold their ground and achieve **protection by combat,** and they fight with a ferocity and aggressiveness unequaled in the animal kingdom. Some bite with their jaws and others have a powerful sting on the tip of their abdomen. There is an ant that has learned to spray its poison from the sting so that intruders are greeted with a cloud of poisonous vapor when they come too close.

Some insects have **repulsive odors and tastes** that protect them from predators. These may leave an odor on any object which they contact

that remains for quite some time and often a delicious looking berry will have a most disagreeable taste due to its prior contact with a stink bug. The monarch butterfly probably looks as if it would taste good to a bird, but birds only attempt to eat one; after that the monarch is safe because of its bitter taste. The blister beetles have blood that will irritate and raise a blister on the skin of any animal that crushes them.

A final method of protection that might be mentioned is **protective mimicry.** Insects develop body shapes and colors that so closely resemble their surroundings that detection by sight is very difficult. A tomato worm may be on a tomato plant and give evidence of its presence by damage done in feeding, yet a careful examination of the plant may fail to reveal it even though it is two or three inches long. Some butterflies look so much like leaves that they are indistinguishable from them when at rest. Walking sticks look very much like twigs and assume poses identical with the appearance of the twig which they are on. Some caterpillars have spots which appear as two great eyes on their back, which gives them a forbidding appearance. Some insects appear to take advantage of protective adaptations of other insects by mimicking them. The viceroy butterfly is marked very much like the monarch butterfly and it is thought to be let alone by birds who have tried to eat the bitter-flavored monarch.

Insect Voices

When we hear the loud singing of the cicada, the chirping of the cricket, and the buzzing of the bees, we might get the impression that insects are a noisy group of animals, but the great majority of them are mute. None of them have anything like vocal cords that vibrate when air is expelled from their bodies so there are other devices present for sound production in those few that make sounds. One of the most common methods is the scraping of the wing covers or legs. Male crickets scrape their wing covers continuously to produce their singing or strum them to produce the chirping. It is said that the timing of the chirps of a tree cricket is in direct relation to temperature and that the temperature can be ascertained by counting the number of chirps per minute. The katydids also use their wing covers and produce a sound resembling their name. Male grasshoppers, during the mating season, fly in the air above the females, clicking their wing covers together like castanets to produce a very characteristic sound.

The cicadas, also called seventeen-year locusts or dog-day harvest flies, climb trees in the summer and produce a lonesome continuous singing that can be heard at a great distance. These insects have a cavity

formed by a part of the thoracic exoskeleton that extends back over the abdomen. Within this cavity is a membrane that can be stretched and relaxed to make it vibrate at a variable pitch, and the cavity acts as a resonance chamber to amplify and reflect sound.

The humming of insects is an incidental sound accompanying the vibration of the wings in flying, but should be mentioned under insect voices because it is sometimes used as a means of communication among insects. The pitch of the hum depends on the rate of vibration of the wings; a house fly hums in the key of F in the middle octave of a piano. When this particular piano string is struck it vibrates 345 times per second. That means that the house fly's wings must beat up and down 345 times per second. This can be checked by allowing the fly's wings to beat against a rapidly revolving smoked drum and counting the strokes made in one second. In bees the humming varies with the temper of the hive, and a beekeeper can tell by the key of the hum whether a hive is contentedly going about its business or is possibly preparing to swarm. Recent research shows that mosquitoes use the hum of their wings as a means of communication. Greatly amplified recordings have been made which show that they have danger signals, mating calls, and numerous other sounds with a definite meaning.

Insect Reproduction

Reproduction among insects is as highly specialized and variable as the other body functions, so only a survey of some of the most common methods can be presented here. The problem of sexual attraction is an interesting study among this group of animals. Odor is used by many
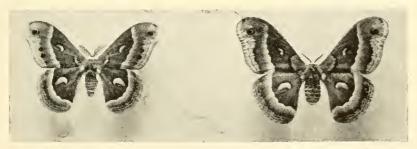
Photo by Winchester

Fig. 15.10. Male and female Cecropia moths. Note the more extensive branching of the antennae of the male. This sexual difference seems to be correlated with the reproduction season when the female exudes an odor which is picked up by the male through the antennae enabling him to find her in the dark.
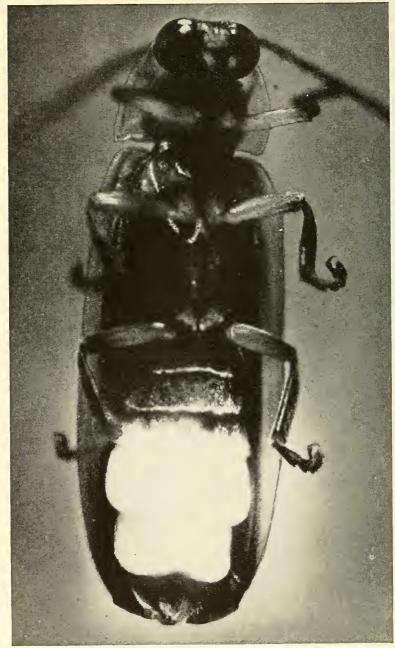
Photo by Winchester

FIG. 15.11. A firefly photographed by its own illumination. Reflectors were arranged around the firefly so that its flash furnished sufficient light to make this picture.

of the females to attract the males. The moths are insects that are active at night and the males might have a hard time finding their mates were it not for a special gland which the females protrude from their bodies when they are ready to mate. This gland has a characteristic scent and a male quite some distance away becomes very excited when he smells it and flies in the direction from which the odor is coming until he finds the female. The antennae seem to be the olfactory organs and are much more extensively branched in the male than the female moth. Some day-flying insects, such as the flies, use sight to find their mates and can usually be recognized by their large well-developed eyes. There is one night-flying insect that also uses sight, the firefly. Fireflies carry their own lanterns with them and give off the flashes of light in order to locate each other in the dark. Many of the sounds made by insects as described under insect voices are made by the males to attract the females. In most cases only the males have the sound apparatus and it serves solely for sexual attraction.

The mating act usually consists of direct copulation with the male inseminating the female, usually only once during her lifetime. Seminal receptacles are frequently present to store the sperms in the female's body to fertilize the eggs as they are laid, sometimes as long as three or four years after insemination, as in the queen bee. The method is slightly different in the dragonflies. Before mating the male loops his abdomen forward and discharges sperms into a little pouch on the second abdominal segment. Then a female joins him in a flight grasping his abdomen with her legs so that they are flying in a tandem fashion with the female behind. During the flight the female will extend her abdomen forward and insert it in the pouch on the male to obtain the sperms which he has placed there.

Reproduction seems to be the main purpose in life for adult insects and they usually die shortly after they have fulfilled their reproductive duties. In the male this is frequently soon after copulation; in the female after egg laying. In other insects, the adults are needed to give care to the young and live to accomplish this important part of reproduction.

Classification and derivation of words given at the close of Chapter 17.

REVIEW QUESTIONS

1. List the insect characteristics.
2. What are the advantages and disadvantages of the insect method of respiration?
3. Distinguish between the three types of insect metamorphosis and give an example of each type.

4. Describe the types of insect wings and the uses of each.
5. What is the relation of insect mouth parts to insect control?
6. Describe the various ways in which insects protect themselves.
7. Tell how crickets produce their sounds.
8. What is the difference in the antennae of male and female moths? What accounts for this difference?
9. Describe reproduction in the dragonflies.
10. How do cicadas make their sounds?
11. Describe the methods used by insects to protect themselves.
12. What is the function of the flashes of light made by fireflies?
13. Distinguish between generalized and restricted feeding habits of insects.
14. One enterprizing entomologist made a recording of the mating call of female mosquitoes. Some have suggested that this could be used as a method of mosquito control. Tell how you think such a recording might be used to destroy mosquitoes.

A Social Insect—The Honeybee

Insects may be conveniently divided into those which are solitary and those which live in organized groups, the social insects. Solitary insects, like the grasshoppers, usually associate with each other only during the mating period and live individualistic lives the remainder of the time. They may be seen in large groups, but the association is casual; they are merely feeding or drinking in the same place. On the other hand, the social insects have a highly developed organization with division of labor among the members of the group and a sharing of the benefits of this labor. In some of these, such as the bumblebees, the groups are small and the organization lasts only a few months; in others, such as the honeybee, they may contain as many as 60,000 individuals and may maintain themselves almost indefinitely. The honeybee is the most useful of the social insects, and a survey of its habits will give us an insight into the habits of social insects in general.

Bee Castes

A typical hive of bees contains three castes: a queen, several hundred drones, and many thousand workers. The **queen** is the largest of the three; she is the only mature female in the colony and she lays eggs for the entire hive. She will lay from one to two thousand a day during the warm months. The **drones** are next in size; they are the mature males and do no work of any kind either in the hive or in the field. When the weather is suitable they make short flights from the hive but are unable to collect either nectar or pollen. They even have to be fed by the workers. They cannot protect the hive for they lack a sting. Their only function in the economy of the hive is to mate with the young virgin queens. The **workers** are the smallest in size; they are imperfect females who perform the many duties of establishing and maintaining the hive.

Duties of House Bees

Workers are divided into two groups: house bees and field bees. For the first three weeks after they are hatched, the workers remain in the

hive performing a great variety of tasks, often changing to a different one when the need for it becomes greater. Actually it has been found, by marking newly hatched bees, that age is the chief factor determining the type of work to be performed.

During the first three days after hatching the bees loaf on the combs containing the brood. This helps keep the larvae warm. After they have cleaned themselves, they start cleaning out the cells from which

Photo by Winchester

FIG. 16.1. The three kinds of honeybees. Queen, above; worker, on the left; and drone, on the right.

other bees have just emerged. From the age of three to six days, the young house bees act as nurses to the older larvae, feeding them a mixure of pollen and honey. From the sixth to the thirteenth day, the glands which secrete the food called royal jelly become active, and these houses bees now feed the younger brood. Some of them may become the queen's attendants. They bring her food and water, carry off her excrement, comb her hairs, and stand ready to care for every need. Actually as the queen moves rapidly over the combs, the attendants change, and she may "beg food" by extending her tongue to any bee she meets. If this worker has food available, she opens her mandibles and allows the queen to drink from her mouth.

The secretion of wax is the chief duty of the house bees from the twelfth to the eighteenth day. Wax glands are located on the underside of the last four abdominal segments of the bees. After they have eaten all the honey they can, they hang from the combs until a wax scale is formed. They now remove this and use it to build part of a cell. Each cell of a comb is composed of six sides, and the cells are arranged in double layers back to back suspended from the roof of the hive or, in modern hives, from the top of each frame. In order to make certain that bees build the combs evenly in the right place, all modern beekeepers place in each frame a thin layer of manufactured foundation with just the base of the cells outlined.

During her third week in the hive the house bee spends as much time as necessary cleaning out the hive. She drags out dead bees, dirt, or any other debris that may have accumulated in the hive. The hives are kept as clean and spotless as possible. If a larger animal, such as a mouse, is stung to death in the hive, and it is too large to be moved out, it is covered over with a gummy secretion called propolis which serves to embalm it.

Almost any bee will act as a fanner when the hive becomes too hot. Fanning is necessary to carry out the excess moisture in the honey. The bees station themselves on one side of the entrance in rows and fan their wings so vigorously that a current of air circulates through the hive. This also prevents the hive from over-heating and melting the wax. The current of air may be strong enough to blow out a candle.

The nectar, as the bees collect it, is thin and watery, often containing as much as 70 to 75 per cent water. When a field bee brings in a load of nectar, she passes it to several house bees who manipulate it in their mouth parts in such a way as to expose it in a thin film to the warm dry air circulating in the hive. If still too watery, it is often deposited in small droplets on the top wall of empty cells where more water evaporates. It is now known as unripe honey, and it is eventually deposited in the cells still in this condition. Evaporation continues until the concentration of water is only from 18 to 20 per cent—it is now honey. The house bees then seal it in the cell with a cap of wax.

Groups of the oldest house bees stand guard near the main entrance and at any cracks or openings. These are the guards or policemen of the hive, and they are ever ready to sting any intruder. They readily fly to investigate any disturbance and may attack animals several feet from the hive entrance. The remainder of the house bees are very mild mannered and usually do not sting unless actually squeezed or injured. One of the main tasks of the guards is to allow

the thousands of bees that belong in the hive to pass through, at the same time keeping out strange bees which might be bent on robbing. If a bee from another hive does attempt to enter, she is seized by the guards who pull her around by her legs and wings until she is glad enough to escape. If the intruder persist she may be stung to death, but this rarely happens. It would seem to be an impossible task to distinguish a foreign bee from the many thousand bees that belong in the hive. Yet this is done easily by the sense of smell; each hive has its own peculiar odor which is imparted to all the bees living within it. When they suspect enemy infiltration, the guards will seize each bee as she arrives. If she smells like a resident, they will let her pass, but they will notice the strange odor of a robber bee and drag her roughly away from the entrance.

Further evidence that bees recognize each other by the sense of smell is furnished by the method used to unite two weak colonies in order to make one strong hive. A layer of newspapers is placed over the first hive and the second hive is set directly on it. By the time the bees have eaten holes in the paper, both sets have come to smell alike and they mingle together peacefully. If the two hives had been united directly, there would have been a fierce battle with many of the bees being injured or killed. One of the queens can be removed in advance or both left to fight it out for supremacy, since no queen will tolerate a rival for long. The queen bee is not injured when she stings since she can remove her sting with ease. A worker bee, on the other hand, has a barbed sting, and when she flies away, after stinging a victim, not only the sting and the attached poison sacs but often most of the digestive system are pulled out of the unfortunate insect. As a result the worker bee is capable of only that one sting and soon dies.

Duties of Field Bees

From the point of view of a beekeeper the most important activity of the honeybee is the collection of nectar. After a bee has completed its tour of duty in the hive, she becomes a field bee and retains this position for the rest of her life. Field bees can be divided into three groups: water carriers, pollen carriers, and nectar carriers. The majority of bright colored flowers have nectaries which secrete a sweet fluid. The male organs of flowers, the stamens, produce large quantities of pollen. Bees, visiting the flowers to collect one or the other of these nutritious substances, accidentally carry the pollen from one flower to another, thus cross-pollinating them. This is a case of symbiosis between members of two different kingdoms, the animal kingdom and the plant kingdom.

A rather peculiar habit of the honeybees makes this particularly effective; they visit only one species of flower as long as it continues to yield nectar in copious quantities. They will have to visit many flowers in order to obtain a full load of nectar, but even though there are several other kinds of flowers in bloom in the vicinity, they remain faithful to a particular species. The reproductive organs of flowers are arranged in such a way that the bees will get the pollen on a certain part of their bodies while visiting the first flower and then brush that part against the female organ of another flower as they enter it.

Photo by Cornelia Clarke

FIG. 16.2. A worker with her pollen baskets full takes off from a flower to carry her precious cargo back to the hive. The pollen adds the needed protein to the diet of the bees.

The bee will visit flower after flower until she has filled her honey stomach. Then she will fly up a few feet, circle once or twice as if checking her direction, and then make a "beeline" for the hive. The flight is so direct that the location of a wild colony of bees may be discovered by watching some of them gathering nectar and then following their direction of flight.

The Dance of the Bees

Upon arriving at the hive they perform a peculiar dance upon the honeycombs. This dance of the bees has excited a great deal of interest

since it was first described by K. von Frisch, a German entomologist, in 1920. The honeybee returning with a load of nectar starts running around the comb in circles, first in one direction and then in the other. After each circle she runs across it at an angle, usually wagging her abdomen vigorously. The number of "wag-tail runs" per minute has been shown to indicate the distance away of the supply, 40 per minute meaning a little over 75 yards and their number decreasing until only about eight runs are performed if the nectar supply is 3.7 miles away. When the food source is less than 75 yards, the bees omit the wag-tail part and merely run in circles on the combs.

Bees also indicate the direction in which they have found a supply of nectar. After completing a circle if the bee runs straight up, it means fly toward the sun; if the bee runs straight down on the comb, it means fly away from the sun. If the bee runs 70 degrees to the left of vertical, it means the feeding place is 70 degrees to the left of the sun; if the bee runs 80 degrees to the right of vertical, it signifies that the food is located 80 degrees to the right of the sun. As the day advances and the sun changes position, the dancing bee shifts her angle accordingly. As the loaded bee dances, field bees come up and follow her closely, getting not only the direction of the honey source but also the scent of the flower from which the nectar came. They leave the hive one or two at a time, before the dancing bee has deposited her load, which shows clearly that they do not follow her as was formerly believed.

Nectar and Pollen Collection

Bees also have a scent organ near the posterior end of their abdomen. When they find a particularly attractive source of food, they open this scent organ and discharge the odor over the food. This added odor is very attractive to bees, and is particularly useful when sprayed on a flower which has no natural scent.

Bees work so hard during the main honey flows that they live only five or six weeks; they literally work themselves to death, and few ever live to benefit from the surplus honey. It takes about 20,000 round trips to collect enough nectar to make a pound of honey, yet one hive can produce 200 to 300 pounds in a good season, with the record yield being over 600 pounds.

Honey is a carbohydrate and is very easily digested, because enzymes secreted by the stomachs of the bees break down the sugar, sucrose, in the nectar into two simple sugars, levulose and dextrose. These simple sugars are ready to be utilized by the body and furnish almost instant energy. However, all animals need some protein con-

taining the important mineral nitrogen in their diet. This is obtained by bees from the pollen. Many of the field workers concentrate on the gathering of pollen. When they land on a flower, such as the rose, they run rapidly over the flower shaking the pollen onto their legs and hairy bodies. They often seize an anther and work it over. All the time the movements of the legs are concentrating the pollen into the pollen baskets on the flattened surface of the hind tibia. Special brushes on the basal segments of the tarsi collect the pollen from the hairs on the body, and special rakes between the tibia and tarsus of the third leg pick up this pollen. As the leg bends at this joint, the pollen is pushed up into the basket by the upper flattened surface of the first tarsal segment.

When the pollen baskets are full, the bee returns to the hive and performs a dance on the combs similar to that of the nectar-gathering bee. She then packs the pollen into special cells generally near the developing brood.
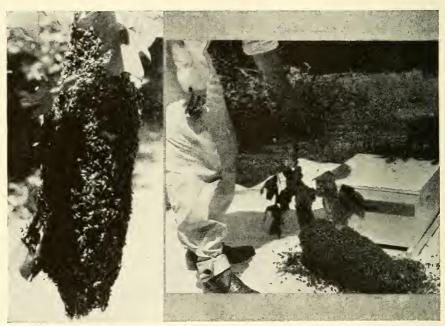
Still other workers are water gatherers and bring in loads of water which are used chiefly by the nurse bees which are feeding the younger larvae.

Swarming

In a healthy hive the number of bees will increase rapidly in the spring, and there will soon be more bees than the hive can accommodate. When the crowding becomes acute, about half of the bees will leave the hive with the queen and establish a new location. This mass migration is called swarming. In preparation for swarming, the workers have built several queen cells. These provide a new queen to replace the one that goes with the swarm. Both the workers and queens are females, but the workers do not mature sexually.

Several days before the new queen is ready to emerge from her cell, about half of the older workers and the drones will leave the hive and start a swarm. The queen soon joins the bees which fly around in circles near the hive. Within a few minutes the bees begin to settle on the horizontal branch of a tree or some similar support. The queen alights with the first bees and soon the other bees pile on top of her until they form a solid mass of bees a foot or so in diameter. The bees at this time are very docile and a person can walk among them with almost no danger of being stung. This is due to the fact that the workers filled their honey stomachs before leaving to have a supply of food to start their new colony.

A swarm is easy to hive. The beekeeper can place an empty hive beneath the limb and shake the bees either into it or in front of it, or he

can saw off the limb and carry the swarm to the hive. If the tree is too valuable to be cut, he can shake the bees into a basket and they will remain there until he carries them to the empty hive. A little honey or some sugar syrup will help entice the bees in. However, it is the queen who must make the decision. If she stays so do the bees, but if she decides to look elsewhere all the bees will follow her.

Courtesy U. S. Dept. of Agriculture, Bureau of Entomology

FIG. 16.3. A swarm of bees. This huge ball of bees has settled on the limb of a tree with the queen in the center. When placed in front of a fresh, clean hive they will go in and establish a colony.

If the swarm is left in the tree, the bees will send out scouts to look for a new location. When they have found such a spot, a hollow tree in most cases, the whole colony will follow them and establish themselves there.

Nuptial Flight

Back in the old hive a very important event will soon take place, the hatching of the new queen. As soon as the first queen cell gives up its contents, the young virgin will seek out and kill all the other unborn queens. She will then remain around the hive five or six days preparing for her "nuptial flight." When the weather outside is favorable, she

will leave the hive and begin flying up in the air. Drones from this and other hives follow her. The strong-flying queen rises higher and higher followed by a cone-shaped column of suitors until finally one of the strongest of the drones catches her. As they mate his copulatory organs burst from his body and remain in the genital organs of the queen. After a few seconds the two fall to earth, where the queen quickly breaks loose from her dying suitor. The sperms in the male
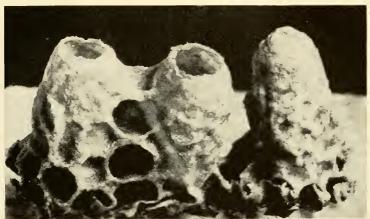
Photo by Winchester

Fig. 16.4. Queen cells. These cells were built in a hive from which the queen had been removed. The one on the right has been capped over, the other two are still open.

genitalia are pumped into the female reservoir, the spermatheca, over a period of several hours. Within a half hour the queen returns with the remains of the male organs still protruding from her body. These are later removed by the queen or some of her attendants.

Control of Sex of Offspring

Within two to three days after mating the queen begins to lay eggs. Human beings have long searched for a means of predetermining the sex of their children and their domestic animals. Several techniques have been tried but as yet give little promise of success. However, the queen bee is able to lay eggs that will develop into males or females as the occasion demands. Since the drones are entirely useless most of the year, it would be a great disadvantage to have the sexes in equal proportions. The worker bees make two sizes of cells, a small size for worker eggs, and a larger size for drone eggs. Apparently the size of the cell stimulates the queen to lay either fertilized eggs (in the small

cells) or unfertilized eggs (in the larger cells). As the egg passes the spermetheca it receives a few sperms which fertilize it if it is to be deposited in a small cell, but a reflex contraction closes the duct from the spermetheca if the cell is large and the egg passes by unfertilized. An unfertilized chick egg will not hatch, but in the bee, it develops into a drone. Thus, we can say that a drone has a grandfather but no father.

The fertile eggs hatch into larvae which may develop into either workers or queens. Usually they develop into workers, but if a queen is needed, the workers will enlarge a cell containing a recently laid egg until it looks like the shell of a peanut hanging over the side of the comb. All the larvae are fed a secretion produced by the nurse bees called "royal jelly" for the first three days. After that the larvae in the queen cell are given much larger amounts of this food and grow much faster and larger (there is some disagreement over the type of food fed the queen larvae). This extra food and space make it possible for them to mature sexually. A queen will develop from egg to adult in about sixteen days, whereas the smaller worker requires twenty-one days.

If a queen should die or be killed, the workers will immediately enlarge several of the worker cells which still contain eggs recently laid. Sixteen days later the first queen to emerge will destroy her rivals as described above. But sometimes two queens emerge at the same time and then the only course is to fight to the death. The successful queen stings her rival, but since her sting is not barbed, she can remove it from the body of her victim. The workers which had formed a circle around the fighters, drag out the body of the loser and accept the winner as their queen. Here we see that the fittest has survived in the struggle for existence.

Beekeeping

It is necessary that the beekeeper arrange the top sections or supers on a hive in such a way that the bees will raise their brood in the lower chambers and store the honey in the upper chambers. Modern hives have ten removable frames in each chamber. Between the lower and upper divisions is a queen excluder, which has a series of holes that will allow the smaller workers to pass through but will exclude the queen. As a result the honey is made clean and pure, free from the brood. When the cells are all full and capped over, the beekeeper has two good methods for obtaining the honey free of bees. He may place a bee excluder in place of the queen excluder. This will allow the bees to go down into the brood chamber but will prevent their return; it is a one-way funnel. Twenty-four hours later the honey can be removed with hardly a bee left in the supers above the excluder.

The second method is by means of an acid board. A piece of cloth is tied over a metal frame the size of the hive top. Carbolic acid is sprinkled on the board and the combination laid over the open hive. If the day is warm and sunny, the acid will evaporate as the metal becomes hot, and the strong fumes will drive the bees down into the brood chamber. Only five to ten minutes is necessary for the acid to drive the bees down from the honey.

The color and flavor of the honey depend upon the species of flowers from which the nectar is gathered. The color varies from water-white of vetch, basswood, or locust, through white of the clovers and alfalfa, to the light amber of tupelo and gallberry, to amber of rattan and buck-
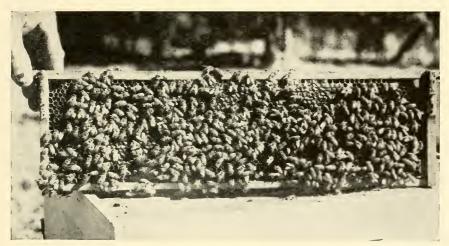
Photo by Winchester

FIG. 16.5. Close-up of one of the honey storage sections of a beehive.

wheat. Buckwheat produces a nearly black honey with a strong flavor, but in spite of this it is very popular in New York state. Each part of the country has a honey which is especially popular locally. In Florida it is orange blossom, in southern Georgia it is gallberry, in California it is sage, in the southern Alleghenies it is sourwood honey, in Washington the honey from firewood is most popular. However, over most of the eastern part of North America, clover honey is the most esteemed as well as the most abundant. Today most of the honey is sold in liquid form, although comb honey is still produced in some localities and brings higher prices.

Beekeeping today has become a big business. Enterprising operators move their bees from one place to another as different plants bloom. Fruit growers and other farmers hire beekeepers to move hives often

to their orchards to pollinate the crops. Proper pollination will usually increase a crop two- or threefold and occasionally as much as tenfold. Many beekeepers make more money from pollination contracts than they do from their honey.

Just as squirrels store nuts, bees instinctively store honey to tide the colonies through the winter. Therefore a beekeeper must leave forty to fifty pounds of it in the hive for winter use. However, since a strong hive during a good season will store five to ten times more than is needed to winter the colony, we can harvest the surplus without harm to the bees. Some beekeepers feed their bees on sugar water during the winter, especially when they want to start early brood rearing in the spring.

Wintering

When winter approaches, the bees change their habits. Since the drones are no longer needed, they are dragged from the hive and left to starve. The presence of drones in the winter would only use up stores, and they would not help in the work of the hive in the early spring. The workers form a ball around the queen and they generate enough body heat to keep the group from freezing. Those on the outside of the ball are constantly crawling inward where it is warmer. The queen remains near the center where it is warmest. In extremely cold weather some of the bees on the outside may be so numbed with cold that they fall off, but the indispensable queen is protected at all times. Even in the winter the queen will lay a few eggs on the combs which are kept warm by the mass of bees so in this way a few young bees are constantly being added. Bees cannot defecate in the hive, but because of the purity of most honey, there is little waste to accumulate. On every warm day in the winter, however, they make a cleansing flight during which any indigestible materials that have accumulated in their intestines are discharged. Impure sweets such as fruit juices will kill the bees during prolonged cold weather since the bees cannot fly out and rid themselves of the feces which accumulate.

Bee Learning

Various studies of the honeybees have been made which seem to indicate that they are among the most intelligent of the invertebrates. They can be trained to visit a blue card on which there is a drop of odorless sugar solution, and they are able to select this particular colored card from a variety of cards of other colors no matter how often its position is changed. Although they cannot reach the nectar in the long

tubes of Virginia bluebell and usually pay no attention to it, when the tubes of the corolla are punctured by carpenter bees, some scout bee will discover this shortcut to the nectar and soon the flowers will be alive with honeybees. When honeybees are used to pollinate alfalfa, they visit the flowers in the proper way to pollinate them for the first few days. However, it is very difficult for a honeybee to force its head into the center of the flower and trip the pollinating mechanism. Eventually the bees discover a shortcut to the nectar through the sides of the corolla tube which are not fused and soon all the bees are "robbing" the flowers without pollinating them. After this it is necessary to remove the hives and bring in new ones, if the crop is to be pollinated effectually. Bees also have a time sense as shown by their visits to buckwheat, which yields nectar only in the morning and early afternoon. About 2 P.M. the flowers have become nectarless and the bees remain in the hive the rest of the day, only to return to the field the next morning, bright and early, when nectar is again abundant.

Most of the activities of the honeybee are instinctive and not the result of either logical reasoning or learning. Whenever a certain stimulus is given, a certain response results. The age of the hive bee seems to determine what instincts shall predominate. It has been claimed that only the honeybee of all animals beside man has mathematical ability. Even this is probably largely a matter of instinct, as there seems to be no way that a bee could have learned to follow the angles made by dancing bees on the combs.

REVIEW QUESTIONS

1. What two factors determine the sort of work a house bee does?
2. Describe wax formation in the house bee.
3. How do beekeepers control the position of the combs in the hive?
4. What two functions are performed by the fanners?
5. How do the guards recognize members of their own hive in contrast to enemy bees seeking to gain entrance to the hive?
6. How does the sting of the queen differ from that of the worker?
7. What are the three duties of the field bees?
8. How does the honeybee cross-pollinate flowers?
9. Describe the dance of the honeybee and explain how both the distance and direction of the nectar source are indicated.
10. What factors determine the time of swarming?
11. Describe the nuptial flight of the queen.
12. How does the queen bee determine sex? Why is this activity especially important in this species?
13. How do the bees obtain a new queen in case their queen dies?
14. What determines the color and flavor of honey?

17

Insect Orders

The insects are a very extensive and diverse class of animals and they affect man in many ways. Over 700,000 species have been described from all parts of the world. Because of this it is worth while to survey some of the more important orders of this group. Some of the lesser known orders are omitted and, of course, all of the different kinds of insects within the orders listed are not given. Nevertheless, this survey includes the order names, the outstanding characteristics of the orders, and a list of interesting features of insects commonly encountered by the average person. Scientific names are given for the orders, but common names are used for smaller groups.

Order—Thysanura

This order contains very primitive insects known as bristletails, fish-moths, etc. They have no wings and no metamorphosis. They have rudimentary appendages on the abdominal segments which suggests that they are related to the annelid worms. They have biting mouth parts. The silverfish is covered with silvery scales and has three long appendages, called cerci, on its posterior end. These insects live on the starch in clothing and book bindings and may also eat paper. They often do considerable damage to stored books, papers, and clothing before their presence is discovered.

Order—Collembola

This order contains the springtails. Superficially they resemble the Thysanura in lacking metamorphosis and wings. They were formerly placed in the same order which was known as the Aptera. Members of this order may have biting or sucking mouth parts. Springtails are quite a nuisance to maple syrup producers because they often land in the syrup buckets hanging on the trees. Some of them are known as snow fleas because they emerge from their winter hibernation so early that they often fall in the snow in vast numbers. They have a springing organ on the underside of the fourth segment of the abdomen.

Order—Ephemerida

These are the May flies which come out in the late spring or early summer by the thousands. They join in a dancing flight up and down in the air which ends in mating, after which the females deposit their eggs on or in the water and then die, usually no more than twelve hours after attaining adulthood. They usually emerge at about dusk and are

Photo by Winchester

FIG. 17.1. The May fly. After spending up to three years in the water as immature forms, the adults emerge and live but a day or so, only long enough to reproduce.

often attracted to lights, but they may meet their doom in a flame before fulfilling their destiny. The naiads live in the water and develop as long as three years before becoming adults.

They have two pairs of membranous wings, but the hind pair are much smaller than the front pair. There are three long projections, cerci, from the posterior tip of the abdomen which are longer than the body itself. Metamorphosis is incomplete and, since they live such a short time as adults, the mouth parts are vestigial and entirely useless so far as feeding is concerned.

Order—Odonata

This order includes the dragonflies and damsel flies. The adults have two pairs of membranous wings of about equal size. The metamorphosis is incomplete and the naiads live in the water preying on the larvae of many harmful insects. They have biting mouth parts and catch and eat insects which they find in the air.

1. Dragonflies. These are large, strong, and swift insects that dart through the air with great speed, catching mosquitoes and other insects.

Photo by Winchester

Fig. 17.2. The dragonfly.

They have many other names, among which are mosquito hawks, because of their habit of catching mosquitoes, and snake doctors, because of their supposed habit of administering to sick snakes. This last characteristic is pure superstition. They are very beneficial because of the large number of harmful insects that they destroy. A captive dragonfly will eat thirty or forty house flies without pausing.

2. Damsel flies. Built very much like a dragonfly, the damsel fly has a smaller and more slender body. It holds its wings over its back when at rest, whereas the dragonfly holds the wings out to the side of the body. Their habits are similar.

Order—Plecoptera

These are the stone flies. There are two pairs of membranous wings and the hind pair are distinctly larger than the front pair. They have incomplete metamorphosis, and the naiads live in swift running streams and furnish an important source of food for brook trout. They are often used as bait for this fish. They have biting mouth parts and two long cerci projecting from the tip of the abdomen.

Order—Orthoptera

These insects have two pairs of wings, the front pair being tough and leather-like and acting as wing covers, while the hind pair are membranous and are used in flying. The hind pair fold up like a Japanese fan in order to fit under the wing covers. A few are wingless. They have biting mouth parts and gradual metamorphosis.

1. Short-horned grasshoppers. These are the common grasshoppers or locusts that have antennae shorter than the body. They have powerful hind legs and prefer to jump rather than to fly. They are widely distributed and do damage of major importance by eating plants. The females deposit the eggs in loose soil in the late summer or early fall; these hatch in the spring and the young nymphs begin eating on almost any green plant that they can find. They spend most of their time feeding while they are nymphs. The great plagues of locusts mentioned in the Bible were, no doubt, the migratory type of grasshoppers. These grasshoppers have moved through the mid-western states, stripping the leaves from every plant in their pathway.

2. Long-horned grasshoppers. These have antennae that are longer than the body and are held pointing backward so that they arch over the body and extend beyond it. They include the katydids, meadow grasshoppers, camel crickets, and Mormon crickets. The last two are wingless forms. The Mormon cricket gets its name from an incident connected with the founding of the Mormon colony at Salt Lake City. These crickets were about to destroy the crops upon which these pioneers depended when a great horde of sea gulls flew in from the Pacific coast and devoured them, saving the crops.

3. Crickets. The field crickets are the ones best known in this group. Their chirping and singing is a very common sound in the late summer months. They feed on both animal and vegetable material. The mole crickets burrow around under the ground and the front legs are very strong and adapted for this purpose. The tree crickets differ consider-

ably from the other two in appearance. They are small and slender and a pale green color. As their name indicates, they live in trees and start their shrill song at dusk, continuing it far into the night.

4. Roaches. These insects have flattened bodies which enable them to crawl through small cracks. They prefer to run rather than fly, but have functional wings and will fly sometimes when cornered. They usually come out to feed during the night and hide during the day so that a house can be badly infested without the knowledge of its owner.

Photo by Winchester

Fig. 17.3. Ventral view of the large German cockroach. Note the flattened body and the powerful running legs.

5. The mantids. These are commonly called praying mantids or devil-horses. They are large carnivorous insects that are very beneficial because of the great number of harmful insects which they eat. The praying mantis gets its name from the fact that it holds its front legs up in an attitude of prayer, but the name "preying mantis" would be more appropriate since it is probably just waiting for some insect to get within reach so that it can grab it with these legs.

6. The walking sticks. These have long stick-like bodies that are remarkably like twigs upon which they rest. They do some damage by eating leaves, but usually are not present in sufficient numbers to be serious.

Order—Isoptera

These are the termites. The order name means equal wings, and they have two pairs of membranous wings of equal size when they have wings at all, but there are many generations that never have wings. They have gradual metamorphosis and biting mouth parts. Their sole item of diet consists of wood. Wood is composed mainly of cellulose which cannot be digested by the majority of animals, and it would seem that the termites would not fare so well on it. However, they have protozoans living in their intestine that secrete enzymes that can digest the cellulose on which both the protozoan and the termite live. This is another example of symbiosis, for the protozoan receives protection and the chewed up food to eat while the termite gets the wood digested and can exist on this abundant material without much competition from other insects. Their bodies are soft, possessing little pigment which makes them quite sensitive to light, and so they seal any openings that would allow light or dry air to reach their tunnels in the wood.

In the tropics they are extremely destructive; so much so that in some places houses cannot be constructed of wood. They are quite common in most of the southern states and seem to be extending their habitat as far north as the Canadian border.

They are social insects with an organization of tasks somewhat like the honeybee. There is a single queen and many workers of both sexes. Each year a winged generation is produced with pigmented bodies; these fly out of the nest, mate, and establish other colonies.

Order—Dermaptera

These insects are commonly called earwigs due to the mistaken notion that they crawl into the ears of sleeping persons and bore into their brains to cause death. Some are without wings, but those that have them have a leathery front pair and a membranous hind pair that are folded both lengthwise and crosswise to fit under the front pair. The metamorphosis is gradual, and the mouth parts are for biting. There are a pair of forceps-like cerci at the posterior tip of the abdomen. They feed on plants and do considerable damage where they are abundant.

Order—Coleoptera

This is by far the largest order of insects—it includes those insects known as beetles. The front wings are horny and serve as wing covers for the membranous hind wings which fold up underneath. When fly-

ing, the front wings are held out to the side of the body like wings of an airplane while the membranous pair provide the power. When beetles are not flying, the front wings meet in a line down the back and the membranous hind pair is so perfectly hidden that it is often thought that beetles do not have wings. The metamorphosis is complete, and many of the larvae are called grubs. The mouth parts are for biting.

1. Tiger beetles. These are aggressive insects that run down and kill their prey which usually consist of other insects. Their bodies are often of brilliant metallic shades of green or bronze.

Courtesy General Biological Supply House

Fig. 17.4. An earwig. The old superstition that this insect would crawl into the ears of sleeping persons is false, but the name is retained.

2. Ground beetles. These are small black or brown beetles that have flattened bodies which enable them to crawl under logs and stones. They are one of the farmer's greatest friends because they destroy many insects that are harmful.

3. Whirligig beetles. Small compact black beetles that whirl around in circles on the surface of the water and catch any insects that happen to fall in are called "whirligig beetles." They walk on the surface film of the water which has enough resistance to prevent their sinking.

4. Carrion beetles. These feed on dead animals and are sometimes called burying beetles, because they excavate under the body of a dead

animal in order to get at it from underneath and, in the course of time, the carcass of the animal will sink below the surface of the ground.

5. Larder beetles. These are found in stored cured meat and cause great loss. They sometimes get in insect collections and do great damage to the dried insects.

6. Click beetles. These are large elongated beetles some of which have what appears to be two huge eyes on the thorax. They get their name from their habit of suddenly clicking the joint between the thorax

Photo by Winchester

FIG. 17.5. A click beetle. This interesting insect has the habit of snapping itself suddenly at the connection between the thorax and abdomen so that it throws itself several inches in the air when disturbed. It also uses this method to right itself when turned on its back. The large "eyes" on the thorax are not the real eyes. They are on the small head in front.

and abdomen when they get on their back. This throws them several inches in the air and they try to land on their feet.

7. Fireflies. These are also called lightning bugs because of their habit of giving out flashes of light from the ventral surface of their abdomen as they fly at night. Some of the larvae also give out light and are called glowworms.

8. Tumble bugs. These collect manure and roll it into a ball and push it to a hole in the ground and lay their eggs with it. Thus, the larvae will be able to feed on it when they hatch out. They sometimes

have vicious fights when one female tries to rob another of a nicely rolled ball of manure.

9. June bugs. Possibly the most common of all beetles. The larvae are the destructive white grub worms which feed on plant roots. The adults are either brown or green and are attracted to lights on warm summer evenings, often flying into rooms through open windows where they create quite a confusion with their buzzing around and bumping into walls. The adults feed on the leaves of trees or suck the juice from berries.
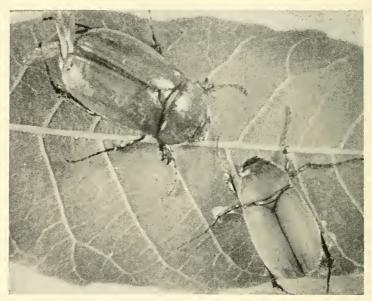
Photo by Winchester

FIG. 17.6. June bugs. These insects spend their larval existence underground as destructive grub worms and the adults do considerable damage feeding on the leaves of the trees.

10. Potato beetles. These small compact beetles eat the leaves of potato and related plants.

11. Meal worm. The larvae live in stored grain and destroy much valuable food, especially stored meal. Although they are usually very destructive, they are sometimes raised commercially as a food for soft-billed birds.

12. Blister beetles. The blood of these is poisonous and will raise blisters on human skin. They once were used to make an ointment that would blister a person's chest when rubbed on as a treatment for a chest

cold. They are still used in very small quantities in hair tonics to give them a stimulating effect on the scalp.

13. The weevils. This group of beetles has jaws modified into snouts. They destroy apples, strawberries, sweet potatoes, and the developing squares and bolls of cotton. The cotton boll weevil claims a large proportion of our cotton crop each year.

Order—Mallophaga

These are usually called the biting bird lice, although just biting lice would be more appropriate since they do not restrict themselves to birds by any means. As the name indicates, they have biting mouth parts with which they eat feathers, hair, or bits of skin that scale off. They are wingless and have gradual metamorphosis. City people often dream of accumulating a little money and retiring to a small farm and making a living raising chickens. They often fail to take the lice and many other bird parasites into account. It takes hard work on the part of poultrymen to keep them under control.

Order—Anoplura

These are the true lice or sucking lice as distinguished from the biting bird lice and plant lice. They have strong beaks for piercing the skin. The metamorphosis is gradual and they have no wings.

1. Head louse. This louse lives on the head of man and lays eggs in nits on the hairs which, when abundant, cause the hairs to stick together and become matted so that the hair cannot be combed.

2. Body louse. During World War I body lice, or cooties as they were somewhat affectionately called by the soldiers, were considered one of the necessary inconveniences of life at the fighting fronts. During World War II, our troops were relatively free of this parasite because of a vigorous "delousing" campaign with DDT, that accompanied the men wherever they went.

These lice lay their eggs in the seams of the clothing and crawl on the surface of the skin, causing a tickling sensation that is quite worrisome. Their great harm, however, comes from the fact that they spread typhus fever.

3. Crab louse. These lice live on the hair around the reproductive organs and are often thought of as a venereal infection since they are usually spread by sexual contact.

Order—Hemiptera

These are the bugs. The word "bug" is used loosely to refer to all insects and to many things that are not insects, but only members of this order can rightfully claim this title. The front wings are distinctive of the group; they are thickened and leather-like at the anterior half, but thin and membranous at the posterior half. They are held so that they overlap on the back when they are not flying. Mouth parts are for sucking, and metamorphosis is gradual.

Photo by Winchester

FIG. 17.7. A stink bug. This bug shows the typical shield-shaped body that is characteristic of the stink bugs. They are quite destructive to plants and emit a very disagreeable odor, especially when crushed.

1. Aquatic bugs. These include the giant water bug that may grow two inches long, the water boatman, back swimmers, water scorpions, and water striders that walk on the surface of the water.

2. Predacious bugs. These include the assassin bug that feeds on soft-bodied insects, ambush bug that crawls in flowers and waits for some insect to enter in search of nectar, and kissing bug that has been known to pierce the lips of sleeping persons to suck their blood.

3. Bedbugs. These common pests make themselves at home in mattresses and other parts of the bed and surroundings and come out to suck the blood of a person settled for the night. Thorough fumigation is about the only means of eradication once they get started.

4. Stink bugs. These are shield-shaped bugs that suck plant juices and have a pronounced, unpleasant odor. They are often found on berry vines and may leave their odor and taste on berries.

5. Plant bugs. These bugs are somewhat elongated with antennae about half as long as the body. The squash bug and chinch bug are common examples. They do serious damage to plants.

Order—Homoptera

These insects have four membranous wings when they have wings, but some have wingless generations. Metamorphosis is gradual, and mouth parts are for sucking. The winged forms hold the wings sloping down the sides of the body somewhat like the roof of a house when at rest.

Photo by Winchester

Fig. 17.8. The cicada or locust. This is the insect that produces the lonesome singing from the trees in the late summer.
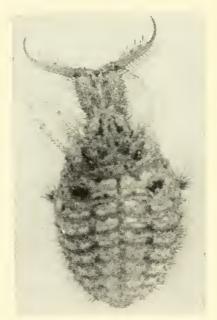
1. Cicadas. The cicada, dog day harvest fly, or locust is the insect that produces the loud singing noises that are so prevalent in the late summer. They live about two years in the ground as nymphs, feeding on plant roots. Then they crawl up on a tree trunk and go through their final molt and emerge as adults. Another species spends seventeen years in the ground and is called the seventeen-year locust.

2. Plant hoppers. These are small hump-back insects that hop when disturbed. They may be referred to as leaf hoppers, tree hoppers, or frog hoppers. They do great damage to plants upon 'which they feed.

3. Plant lice. These are the aphids that are used as cows by the ants. Some generations are wingless. They live on the underneath side of leaves and make up for their small size by their tremendous numbers which do great damage to plants. Eggs hatch within the body of the females and the young are born alive, with ten generations or more each

season. It is fortunate that they have many enemies that keep them in check or they could soon devour every plant on the earth.

4. Scale insects. These are serious plant parasites. The nymphs form a hard protective scale over their bodies and suck the plant sap. Some produce a soft cottony covering and are called mealy bugs. The adults are winged forms.

Order—Neuroptera

This order name means nerve wing and is given because of the many branched delicate veins or "nerves" in the wings. There are four of these membranous wings of equal size, complete metamorphosis, and

Courtesy General Biological Supply House

FIG. 17.9. Ant lion or doodlebug. This ferocious looking animal is the larva of the delicate lacewing fly. It builds a funnel of dirt in soft ground and holds its jaws open at the bottom waiting for ants or other insects that may slip over the side.

biting mouth parts. The larvae are carnivorous and are armed with powerful jaws with which they destroy many harmful insects.

1. Aphis lion. The adult of this insect has beautiful, pastel-green wings that have earned for it the name lacewing fly. The larvae, on the other hand, are vicious carnivores that kill and eat plant lice, aphids, by the hundreds. They have such a ravenous appetite that the female lays

each egg separately and puts it on a tall stalk and the first larva to hatch cannot eat its brothers and sisters in their egg cases. They are extremely beneficial because the aphids are one of the most destructive of the plant parasites and some wise gardeners gather the adults with an insect net and release them in their garden.
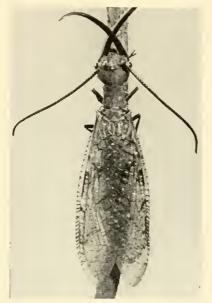
Photo by Winchester

FIG. 17.10. A dobson fly. The long jaws shown are found only in the male and are used to embrace the female when mating. The larvae live in water and are called hellgrammites. They make excellent fish bait.

2. Ant lion. The adults of this insect are somewhat larger and more stockily built than the aphis lion adults. Eggs are laid in dry loose dirt and hatch into the familiar ant lion, or doodlebug, that builds a cone-shaped pit in the dirt and waits for an ant, or other insect, to venture over the edge of this trap. When this happens, the insect finds that the harder it struggles to get out the faster it slips to the point of the cone where the jaws of the ant lion are waiting to crush and devour it.

3. Scorpion flies. These get their name from the fact that the male has claspers at the tip of its abdomen that make it look somewhat like a scorpion, but it has no sting.

4. Caddis flies. The adults look somewhat like moths with fine hairs on their wings that resemble scales of the moths. The larvae live in

water and some have a habit of covering their bodies with sticks, gravel, and shells which adhere to them for protection.

5. Dobson flies. The adult is a large vicious looking, but harmless insect. The larvae live in water and are called hellgrammites by fishermen who consider them excellent fish bait, especially for bass.

Order—Lepidoptera

These are the butterflies and moths. They have two pairs of large membranous wings, which are covered with overlapping scales that come off like a fine powder when they are handled. The mouth parts are for sucking, and the proboscis in some of them may be several inches long
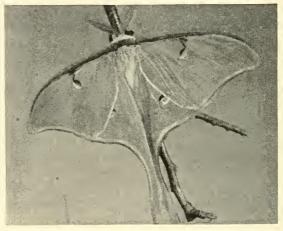
Photo by Winchester

FIG. 17.11. Luna moth. Its beautiful pastel green wings are in contrast to the drab coloration of most of the moths.

and is coiled up under the head when not in use. Metamorphosis is complete; and the larvae are commonly called caterpillars and, unlike the adults, have biting mouth parts. The butterflies are better known than the moths because they fly in the daytime and usually have large colorful wings that attract attention, but the moths are much more common and their larvae cause great destruction to plants. However, the moths fly at night and are not seen so often. The butterflies bear a knob at the tip of the antennae, whereas the moth antenna is usually feathered or may have a knob just short of the tip. The wings of the butterfly are usually held erect over the back when at rest while those of the moth are held folded down over the body. The moth larvae spin a cocoon

of silk while most butterfly larvae attach themselves by a thread of silk to a twig and the outer body covering hardens to form a chrysalis which serves as their pupa case.

1. Butterflies.
   a. Skippers. Stout bodied, somewhat moth-like and spin a silk cocoon.
   b. Monarchs. The common brown and yellow spotted butterfly.
   c. Sulfur butterflies. Many small forms, yellow and white in color.
   d. Swallowtails. These have a projection from the posterior end of the hind wings and include some of the most beautifully colored butterflies.
   e. Four-footed butterflies. The front legs are small and practically useless as legs so they seem to have only two pair of legs.
   f. The hairstreaks. These are small blue, red, and copper colored butterflies that have fine streaks of hair on their wings.

Courtesy General Biological Supply House

Fig. 17.12. The clothes moth, adult and larva. The little wormlike larva, no more than a quarter of an inch long, is the culprit that does all the damage to stored woolens, furs, feathers, etc.

2. Moths. The list of moths is so extensive that space will not permit a listing of even the most important of the group. The larvae are frequently called worms; silk worms, bag worms, army worms, measuring worms, and tomato worms are a few of these. The clothes moths might be mentioned because of the great destruction that they do to stored clothing and the great expense of protection from them. The adult moth lays its eggs on the clothing and the larvae do the damage.

Order—Diptera
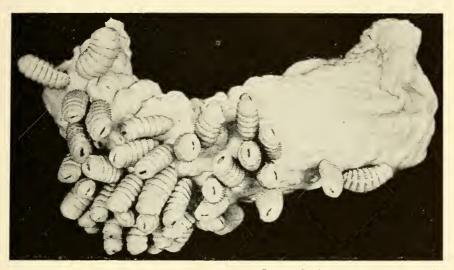
Many members of this order are referred to as flies. They have a complete metamorphosis, and the larvae of many of them are called maggots; whereas those that develop in water are called wigglers. As the order name indicates, they have one pair of functional wings which are membranous and are used for flying. The second pair are rudimentary and are called halteres or balancers and seem to function somewhat like a gyroscope in flight; they seem to help the flies maintain equilibrium in flight. The mouth parts are of the sucking type, but in some species there are also jaws which bite first to draw the blood which is sucked up the proboscis. They may be divided into two main groups: the short-horned flies, which have from three to five segments on their antennae; and the long-horned flies, which have more than five segments.

A. Short-horned flies.

1. Horse flies. Horse flies are usually quite large and bite and suck blood of mammals. Horses seem to be preferred, but they will bite many other mammals including man when they have the opportunity. Some breed in swampy regions and make life almost intolerable for cattle in such regions. They may be quite annoying to bathers on beaches that are near swampy areas.

2. Robber flies. These large, swift insects catch other insects in the air for their food. They destroy many harmful insects, but also catch many honeybees.

3. Bee flies. These look very much like bees in coloring and feed on the nectar of flowers. The larvae are quite beneficial because they feed on grasshopper eggs, grub worms, and other harmful insects that pass part of their life cycle in the ground.

4. The house fly. These are so named because they are found so commonly around the house. They are one of the greatest nuisances to be contended with on the farm. They reproduce readily in manure in the barnyard and come into the kitchen and dining table in spite of screens, flypaper, sprays, and other attempts at control. Because of their unclean habits they spread serious intestinal diseases such as typhoid and dysentery and rank as one of the most serious insect enemies of man.

5. The botflies. These are covered with hairs and look somewhat like bees. The larvae of these are parasites which develop within the bodies of mammals. The horse botfly female lays eggs on the skin of horses and horses lick them off and they develop as maggots in the stomach of the horse and pass out of the horse's body when they pupate. In others, such as cattle and rabbits, the eggs are laid on the skin and

the larvae bore through to form "warbles" or "wolves" and the adult fly eats its way out when it matures.

6. Flesh flies. These live in the decaying flesh of dead animals and some of them are called "blow flies" because they live in and around the bodies of bloated animals. Some are called "screw worms" because the female deposits tiny living larvae in open sores of animals such as horses and cows and they work around in the sore. These are sometimes deposited in the nose of man and work around in the nasal cavity and

FIG. 17.13. Botfly larvae attached to the stomach of a horse. This stomach has been removed after the death of the horse and the inner lining is shown here with the many larvae attached to it.

sinuses until they pupate and eventually fly out of a nostril a full grown fly. Some species are beneficial; it has been found that they will eat only dead flesh and are sometimes put in human wounds to clean out the decaying flesh and speed up healing of the healthy tissue.

7. Tachina flies. Parasites on caterpillars in the larval state. Live larvae are laid on the caterpillar's back by the female tachina fly. These larvae work inside the caterpillar and live on its body. The caterpillar forms a pupa, but a number of dark colored sluggish flies hatch out instead of a moth or butterfly.

8. Tsetse flies. A blood sucking fly that inhabits a large part of Africa and spreads the dread disease of sleeping sickness discussed in detail in Chapter 7.

9. The fruit flies. The tiny little banana fly is one of this group. They may be found buzzing around stalks of bananas or decaying fruit and vegetables. Because of their small size, ease of handling, and short life cycle, they are favorite subjects for studies of heredity.

B. Long-horned flies.

1. Crane flies. These look like huge mosquitoes, but fortunately they do not bite. They have very long fragile legs that come off quite easily when handled.

2. Mosquitoes. These are well known in nearly all parts of the earth. They may even be seen coming up out of the snow as it thaws in the spring in the Arctic Circle. The three main genera are: the *Anopheles,* which spread human malaria; *Culex,* which spreads elephantiasis; *Aedes,* which spreads yellow fever. As a group they are among the greatest enemies that mankind has. The larvae, "wigglers," develop in water.

Photo by Winchester

FIG. 17.14. Mosquito larva. Note the breathing tube at the posterior end of the body which is projected above the water for respiration.

3. Midges. Tiny, but blood-thirsty little insects that can make life miserable for man and beast alike where they are abundant. One species is called the sand fly and spreads the serious tropical disease, Kala azar.

4. Gnats. These tiny worrisome insects often form an inescapable cloud around a person's head and no amount of waving and slapping can drive them away. The females of many species lay their eggs in leaves or twigs of plants and the plant forms a gall at the spot in which the larvae develop. Some develop in mushrooms. The Hessian fly is included in the group. The female lays the eggs at the node of wheat or rye plants, and the maggots live between the stalk and leaf and greatly curtail production since the stem usually breaks at that point. In some years as much as 50 per cent of our wheat crop has been lost to this pest.

Order—Siphonaptera

These are the fleas. As the order name indicates they are wingless forms that have sucking mouth parts. The metamorphosis is complete; they have little worm-like larvae than can exist on such apparently unpalatable substances as the dust that tends to accumulate under a rug. There are cat fleas, rat fleas, and human fleas, but none of them are particular about their host and readily change from rat to man and so on. Their bodies are flattened so that they can easily work themselves through the hairs of their host. They have a powerful sense of smell and a powerful pair of jumping legs so that they can smell their victim coming and give a tremendous leap in that direction. A person can get a nice collection of fleas by tying sticky fly paper around his legs and walking through a flea infested barn.

The "sticktight" fleas are great pests on poultry and sometimes get on them in sufficient numbers to cause their death. Unlike the majority of fleas that like to change hosts, this one usually stays put once it finds a satisfactory host.

The fleas are considerably more than just pests, however, because some of them spread serious diseases such as bubonic plague and typhus fever.

Order—Hymenoptera

This order name means membrane wing and members of this group have two pairs of membranous wings. The front pair are noticeably larger than the hind pair, but all four are used in flying. The metamorphosis is complete and mouth parts are for biting, but may be modified for sucking in some, such as the bees.

1. Bees. These are brightly colored insects with their bodies covered by branched hairs, in comparison with the wasps which have simple hairs. The honeybee was discussed thoroughly in Chapter 16. There are several hundred other species of bees in North America. The bumblebee is one which renders important service in cross-pollinating plants. The important forage crop, red clover, is chiefly dependent upon bumblebees for pollination, because the tubes of the flowers are nearly twice as long as the tongue of the honeybee. Progressive farmers no longer destroy the nests of bumblebees. There are numerous species of small, solitary bees which may be metallic, red, green, or yellow in coloration. They are also valuable in pollination of plants, especially fruit blooms and other crops.

2. Ants. The ants have an advanced social life like the bees and construct nests housing thousands of the members of a single social group.

They have stings and can also bite with their strong mandibles, although there is no poison injected with the bite. Like the termites, they do not need and do not have wings in the generations that are destined to spend their lives as workers in connection with the nest. However, a winged generation will be produced each spring. Both males and females in large numbers will come out of the nest and fly into the air singly and drop to the earth in pairs. As in the bees, copulation occurs as they fall. The male then wanders around aimlessly a short time and, his purpose in life having been accomplished, dies. The female finds a suitable spot to found another nest and digs a shallow hole in the ground and lays her eggs. She bites her wings off since she will not need them any longer. When the first workers emerge they take over the work and the female becomes their queen and concentrates on egg laying for the rest of her life.

Photos by Winchester

FIG. 17.15. Fleas. The larva is shown on the left, the female adult in the center, and the male adult on the right.

Some species of ants have domesticated the aphids, plant lice, and no domestic animals of man receive better care than they. They are carried out to feed on leaves outside of the nest or the ants may build tunnels to the roots of plants so the aphids can feed underground. In return, the aphids secrete a sweet liquid called "honey dew" which the ants eat. This is another excellent case of symbiosis. Some ants chew up leaves which they use as a base for underground gardens of fungi. The fungus is carefully tended by "gardeners" who keep the spore-bearing bodies cut off so the crop will not go to "seed." The ants eat the vegetative part of the fungus plant. There are many varieties of ants with so many different habits and customs that it would require volumes to describe them, but our limitations of space prevent further discussion here.

3. Wasps. The wasps are noted for their powerful stings and their ready use of the sting upon those that intrude upon their privacy. Only

the females sting but, since the sexes cannot readily be distinguished, it is a good idea to show due respect for all of them. They are subdivided as follows:

a. True wasps. These include forms like the red wasps, yellow jackets, and hornets. They make nests by chewing up bits of worn wood and spreading them out in the form of a paste to dry, thus duplicating our wood pulp process for making paper.
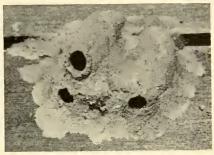
Photo by Winchester

FIG. 17.16. Nest of the mud dauber. This thread-waisted wasp builds its brood chambers of mud, then stings a spider to paralyze it and puts it in a chamber with an egg to furnish fresh food for the larva when it hatches.

b. Thread-waisted wasps. Characterized by an extremely thin connection between the abdomen and thorax which looks little larger than a thread. These include such interesting forms as the mud-daubers that build nests of mud containing several individual cells. After laying an egg in each cell the female will find and sting spiders in their thoracic ganglia so that they are paralyzed but not killed. She will put one or more of these in each cell and seal it up with mud. When the larvae hatch out they find fresh juicy spiders to feed on during their larval development.

c. Digger wasps. These dig holes in the ground and put paralyzed spiders or caterpillars in with the eggs. Some do not have wings and are called velvet ants.

4. Boring hymenoptera. In this group the females are adapted for boring holes in plants or animals to deposit their eggs. Those deposited in plants cause the plant to produce a gall at the spot and the larvae develop in this gall. Others deposit the eggs in the bodies of such animals as spiders or caterpillars and the larvae live as parasites in the body of the host.

Classification and Derivation of Scientific Words

Class Insecta (L. *insectus,* divided; refers to the divided body, body divided into three parts).

Order 1.   Thysanura (Gr. *thysanos,* tassel; *oura,* tail; refers to tail).

Order 2.   Collembola (Gr. *kolla,* glue; *ballo,* part).

Order 3.   Ephemerida (Gr. *ephemeros,* lasting but a day; the adults live but a day).

Order 4.   Odonata (Gr. *odous,* tooth; refers to the toothlike biting mouth parts).

Order 5.   Plecoptera (Gr. *plecos,* plaited; *pteron,* wing; the wings are folded in plaits when not flying).

Order 6.   Orthoptera (Gr. *orthos,* straight; *pteron,* wing; front wings held straight back over the body).

Order 7.   Isoptera (Gr. *isos,* equal; *pteron,* wing; the four wings are of equal size).

Order 8.   Dermaptera (Gr. *derma,* skin; *pteron,* wing; the hind wings resemble skin).

Order 9.   Coleoptera (Gr. *celos,* sheath; *pteron,* wing; the front wings act as a sheath for the hind pair).

Order 10.   Mallophaga (Gr. *mallos,* wool; *phagein,* eat; feed on feathers, hair, and skin).

Order 11.   Anoplura (Gr. *an,* without; *oplon,* sting; *oura,* tail; they do not have a sting on the "tail").

Order 12.   Hemiptera (Gr. *hemi,* half; *pteron,* wing; the front wings are half leather-like and half membranous).

Order 13.   Homoptera (Gr. *homos,* same; *pteron,* wing; wings are of the same thickness throughout their length and width).

Order 14.   Neuroptera (Gr. *neuron,* nerve; *pteron,* wing; the wings are filled with a delicate network of "nerves").

Order 15.   Lepidoptera (Gr. *lepis,* scale; *pteron,* wing; the wings are covered with fine scales).

Order 16.   Diptera (Gr. *dis,* two; *pteron,* wing; there are only two fully developed wings).

Order 17.   Siphonaptera (Gr. *siphon,* a tube; *a,* without; *pteron,* wing; wingless insects that suck the food through a tube or proboscis).

Order 18.   Hymenoptera (Gr. *hymen,* a membrane; *pteron,* wing; have thin membranous wings).

REVIEW QUESTIONS

1.   List the orders of insects with complete, incomplete, and gradual metamorphosis and those with no metamorhposis.

2. Name ten insects that are of economic value and tell how they are of value to man.

3. Name ten insects that are economically harmful and tell how they do harm to man.

4. What is unusual about the mouth parts of the May flies.

5. What special adaptation do the termites have to allow them to derive their nourishment from wood?

6. Where do the click beetles get their name?

7. Why does the aphis lion female lay her eggs on separate stalks?

8. Distinguish between the moths and butterflies.

9. Trace the life cycle of the horse botfly.

10. Describe symbiosis as illustrated by the ants and aphids.

11. Tell how the true wasps make their nests.

12. What are naiads and where do they live?

13. What is the economic importance of the Hessian fly?

14. Why are house flies economically harmful to man?

15. How do the digger wasps feed their young?

16. Why are bumblebees better pollinators of red clover than honeybees?

17. Name three genera of mosquitoes and tell what disease may be spread by each.

18. What are the meanings of the following order names: Orthoptera, Isoptera, Coleoptera, Mallophaga, Hemiptera, Neuroptera, Lepidoptera, Diptera, and Hymenoptera?

19. In what stage of the life cycle is the clothes moth destructive?

20. Name as many kinds of insects as you can that are eaten by human beings.

21. After reading the last two chapters, do you think that insects are primarily beneficial or harmful? Give reasons for your answer.

18

Phyla of Lesser Significance [1]

There are a number of animal groups that are considered as separate phyla; yet, because they are little known, of little economic importance, or have no great biological significance, they do not deserve a thorough study in a survey course. However, in order to make the survey of the animal kingdom complete, they are listed in this chapter together with some of their most important characteristics.

Phylum—Ctenophora

This phylum includes the comb jellies, or the sea walnuts. The first common name is given because they bear eight rows of small ciliated bodies which closely resemble combs and their bodies are jelly-like in consistency. The shape of some of them has given them the name of sea walnuts. They are marine forms which float and swim near the shore, and great numbers are sometimes cast up on the beach by the breakers.

The Ctenophora are sometimes placed in the Coelenterata because their body organization is quite similar to the medusa type in this phylum. However, there are certain important morphological differences that put them in a separate group. The jelly-like mesoglea contains long muscle fiber cells which seem to be forerunners of a mesoderm and the triploblastic body plan as found in the Platyhelminthes. The Ctenophora have a type of symmetry which is called biradial; it is radial in nature, but the parts are equally arranged on two sides so that it bears some relation to the bilateral type of symmetry.

Phylum—Rotifera

This phylum includes a number of interesting microscopic forms that are frequently found in fresh-water cultures along with protozoa. The phylum name means to bear a wheel, and rotifera are commonly called wheel animals because many of them have cilia on disc-shaped projections from the anterior end of the body which beat in such a way that the

[1] This chapter may be omitted without interrupting the continuity of the text if the instructor so desires.

disc seems to be revolving and resembles a wheel turning. They are worm-like in appearance and seem to be closely related to the flatworms and roundworms, having some characteristics of both. For instance, they have flame cells like planaria, but an anus like ascaris.
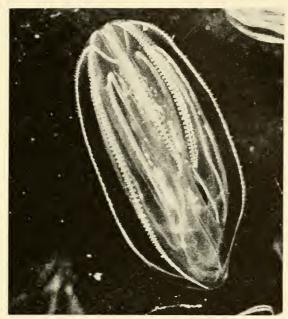
Photo by Buchsbaum

Fig. 18.1. A sea walnut. Photo of living animal at Woods Hole, Mass.

Phylum—Gastrotricha

This is another small group of animals commonly found in fresh water closely associated with amoeba, paramecium, and the rotifers. They do not have the revolving wheels of cilia at the anterior end, but have rows of cilia down their ventral surface for locomotion. A few are also found in salt water.

Phylum—Bryozoa

Animals in this phylum are sometimes called moss animals because they resemble moss-like plants and are often mistaken for seaweed in their marine form. They develop a hard case, somewhat like the coral polyps, and extend themselves from this to feed, only to draw themselves
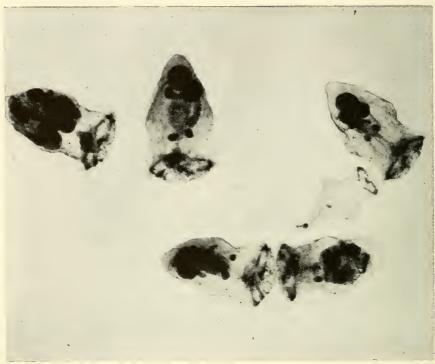
Fig. 18.2.　Rotifers.

back quickly at the slightest sign of danger. Superficial examination might lead to their inclusion with the Coelenterates because of their external similarity to the polyp body shape, but further study reveals a brain and an anus which definitely rank them as being more advanced.

Phylum—Phoronidea

This is a small group of about a dozen species of sessile, marine, worm-like animals that secrete a hard tube in which they dwell. They extend themselves to feed and withdraw into the tube in times of danger like the bryozoans.

Phylum—Brachiopoda

The Brachiopoda bear an external resemblance to bivalved mollusks. They have two valves to their shell held together with a hinge, but there

are many morphological differences.   The two halves of the shell repre-
sent dorsal and ventral surfaces rather than lateral, as in the mollusks ;
and within the shell there is a pair of spirally coiled arms which have no
counterpart in any other phylum.   They are all marine and are able to
move about like the clams, but have a stalk coming out near the hinge of
the shell which they can use for temporary attachment.

Photo by Winchester

Fig. 18.3.   A moss animal, bryozoan.
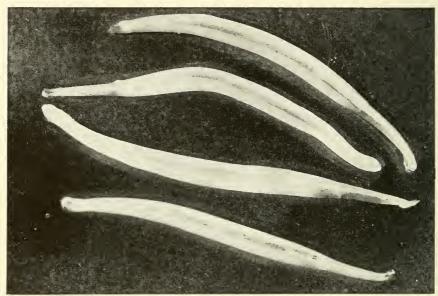
Fig. 18.4.   Arrow worms.

Phylum—Chaetognatha

This phylum includes a small number of species, all of which are marine.   They are slender transparent worm-like creatures that are given the common name of arrow worms.
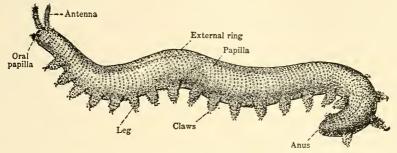
Phylum—Nemertea

This is another phylum of worms which are almost all marine and not commonly seen.   They are of some biological significance, however. They are sometimes placed in the Platyhelminthes, yet they have a digestive tube with two openings and a series of three blood vessels for circulation that seem to set them in advance of the flatworms.   They are commonly called proboscis worms.

Phylum—Onychophora

This phylum includes a single genus, *Peripatus,* which bears many characteristics of the annelids, but it is also similar to the most advanced phylum of the invertebrates, the Arthropoda.   This creates a problem of classification which most authorities feel is best solved by placing it in a

separate phylum. The annelid-like characteristics of *Peripatus* include a thin cuticle which covers the body, paired nephridia in each segment, a dorsal blood vessel, and ciliated reproductive organs. These are characteristics not found in the arthropods. The arthropod-like characteristics

College Zoology, Hegner, The Macmillan Company

Fig. 18.5. Peripatus. This animal bears characteristics of the annelid worms and also the arthropods and seems to form a connecting link between the two.

which are not found in annelids include claws on the appendages, trachea for respiration, and blood sinuses. These features of *Peripatus* cause it to be considered as evidence of annelid ancestry of the arthropods.

Classification and Derivation of Scientific Words

Phylum Ctenophora (Gr. *ktenos,* comb; *phoros,* to bear; these animals bear eight rows of comb-like bodies). Comb jellies, or sea walnuts.

Phylum Rotifera (L. *rota,* wheel; *ferre,* to bear; beating cilia on anterior discs resemble turning wheels). Wheel animals, or rotifers.

Phylum Gastrotricha (Gr. *gaster,* stomach; *trichos,* hair; have tracts of cilia on the ventral surface).

Phylum Bryozoa (Gr. *bryon,* moss; *zoon,* animal; resemble moss). Moss animals.

Phylum Phoronidea (Gr. *Phoronis,* from Greek mythology, a goddess that was changed into a heifer by Zeus).

Phylum Brachiopoda (Gr. *brachion,* arm; *pous,* foot; when first discovered it was thought that the coiled arms were extended out to serve as feet).

Phylum Chaetognatha (Gr. *chaite,* bristle; *gnathos,* jaw; there are bristles on the jaws that aid in capturing food).

Phylum Nemertea (Gr. Nemertes, one of the Nereid nymphs in Greek mythology). The ribbon worms.

Phylum Onychophora (Gr. *onus,* claw; *pherein,* to bear; they bear claws on their legs).

REVIEW QUESTIONS
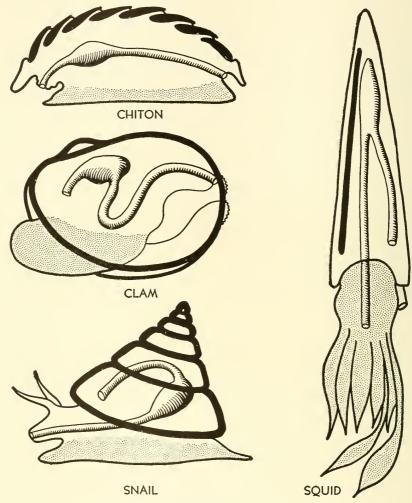
1. Why are the Ctenophora placed in a separate phylum from the Coelenterata?
2. How do the rotifers resemble both flatworms and roundworms?
3. Describe the similarities and differences between the Brachiopoda and the bivalved mollusks.
4. What is the importance of Peripatus in establishing relationships between other phyla?
5. Compare the Nemertea with the flatworms.
6. Compare the Bryozoa with the Coelenterata.
7. Where do the rotifers get their name?

Soft-Bodied Animals—The Mollusks

The phylum Mollusca is very extensive, containing nearly 90,000 species, a greater number than is found in any other phylum except the Arthropoda. The name is derived from a Latin word *mollis,* which means soft and is appropriately chosen in view of the soft body parts of these animals. Most of them have a shell on the outside of the body to protect these delicate organs. Because of the presence of this shell many of the marine forms are called shellfish. The phylum includes such widely divergent forms as the snail, octopus, squid, oyster, and clam. These may not seem to have many characteristics in common that would cause them to be grouped together in the same phylum, but a survey shows them to be quite similar in fundamental structure. They all have a **mantle,** which surrounds a part of the body called the **visceral hump,** that contains important internal organs. All the species that are able to move about have a **foot** as a locomotion organ that extends down ventrally from the visceral hump. The mantle secretes a liquid, which hardens to form a **shell** that surrounds the mantle in most species; but there are some, like the squid, that do not have an external shell, although in these forms the mantle is somewhat tough and offers a degree of protection. The soft bodies of many of them make delicious eating, and the mollusks (common name) furnish us a very important source of food. The Mollusca include a rather highly specialized group of animals that have adopted a pattern of life quite different from other phyla; thus their organ systems show specialization that sets this phylum apart as a side branch of the animal tree.

Class—Pelecypoda

This name means "hatchet foot" and refers to the shape of the foot in these mollusks, but the common name "bivalve" is a little more descriptive because the shell is composed of two halves or valves hinged together at the dorsal surface. Fresh water as well as marine forms are included in this class. They are of great economic value, for not only are most of them edible, but also valuable pearls and mother-of-pearl ornaments are obtained from them.

CHITON

CLAM

SNAIL   SQUID

Animals Without Backbones, Buchsbaum, The University of Chicago Press

FIG. 19.1. The mollusks show a great variation in their plan of body organization, but all have the same body parts which have been modified in various ways to suit the needs of the animal. The digestive system is shaded, the foot is stippled, and the shell is shown by the heavy black line.

A **fresh-water clam,** or mussel, will serve as a good type animal for the phylum and an example of this class. Clams are found widely distributed in the rivers and lakes of the United States wherever there is sufficient lime dissolved in the water to enable them to produce their shells. They are very abundant in the Mississippi Valley where much

of the water filters through limestone deposits and is rich in this important mineral. In this region the clams are collected and their shells used to make "pearl" buttons, such as those found on most men's shirts, "pearl handled" knives and revolvers, and similar ornaments.

The outer surface of the shell is made up of numerous concentric rings. These are **rings of growth** since the rings are deposited by the mantle around the outer rim of the shell to increase its size. A number of rings will be deposited each year, but the rings representing the dormant periods of the winter months are usually more pronounced. Thus, the age of a clam can be estimated. Slightly anterior to the hinge is a little hump called the **umbo** which is encircled on three sides by growth rings, showing that this is the oldest portion of the shell.
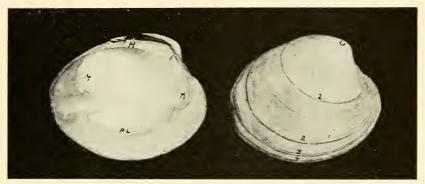
Photo by Winchester

FIG. 19.2. Internal and external views of a clam shell. Note the concentric lines of growth, with heavier lines at the termination of each year's growth. H, hinge; U. point of muscle attachment; P.L., palial line; U, umbo; 1, 2, 3, 4, yearly growth rings.

The outer surface of the shell is covered by a tough and somewhat eroded **horny layer,** but the inside is a very beautiful **pearly layer.** This inner layer has an opalescent quality, reflecting the light waves in their various colors due to the presence of thousands of tiny prismatic bodies which are imbedded in the mother-of-pearl.

The two parts of the shell are closed by a pair of adductor muscles which are so strong that a considerable force is required to pry the shell open. The clam can open it easily, however, by relaxing these muscles and the elastic hinge causes the halves of the shell to swing apart. When the shell is open the clam may extend its foot and pull itself along very slowly in the mud at the bottom of the river or lake where it lives.

There are some unusual developments in the organ systems of the clam which allow it to carry on its life processes in its sluggish state. At

the posterior end of the animal there is a pair of openings which allow water to enter and leave the **mantle cavity,** which is the cavity lying between the **mantle** and the **visceral hump** and **foot.** The ventral opening is the **incurrent siphon,** through which water enters the mantle cavity, and the dorsal opening is the **excurrent siphon,** through which the water
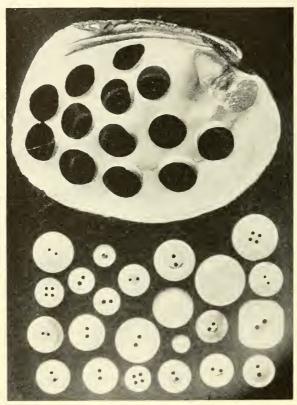
FIG. 19.3. Pearl buttons from fresh-water clam. This photo shows a clam shell that has been drilled out for buttons and a series of different kinds of buttons that are produced from such shells.

leaves. There are a pair of **gills** on either side of the mantle cavity which bear cilia that keep up the circulation of water through the cavity. **Respiration** is carried on by the gills as the water flows through them.

The water coming into the cavity will contain bits of organic matter which can be used as food. There are a pair of **palps** on either side of the mouth at the anterior end of the body which sort out edible particles and carry them into the mouth. **Digestion** takes place in a small **stom-**

ach and absorption through the **intestine**. **Egestion** is through the **anus** which opens just dorsal to the excurrent siphon, so that the waste is carried out without mixing with the water in the mantle cavity.

Excretion is taken care of by a pair of **nephridia** which lie in the dorsal portion of the visceral hump and empty into the water that is on its way out of the dorsal siphon.
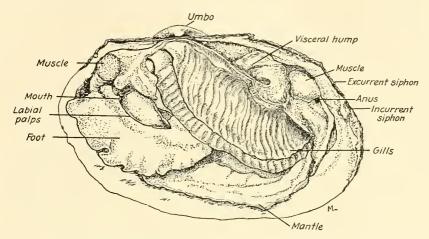
Fig. 19.4. A fresh-water clam with the shell and mantle removed from the left side showing the position of the body organs within the shell.

The **circulatory system** includes a single **heart** and connecting **arteries** and **veins** which transport the blood over the body. Some of the arteries, instead of forming small capillaries which connect with the veins, empty into **blood sinuses,** which are cavities that connect directly with the veins. The blood has no hemoglobin but does have white corpuscles.

The **nervous system** consists of three paired **ganglia** with connecting nerves, smaller nerve branches, and rather poorly developed sense organs. There is a pair of ganglia above the mouth, the **cerebropleural ganglia,** that are the equivalent of the brain, with paired nerves running posteriorly to the **visceral ganglia,** and another pair of nerves running ventrally to the **pedal ganglia** in the foot.

Reproduction in the clam is quite interesting. The sexes are separate and, during the reproductive season, the male releases the sperms through the excurrent siphon, some of which will be taken into the incurrent siphon of the female. In the meantime the female has released her eggs which are held in the gills where they are fertilized by the sperm passing through. The resulting zygotes are held here until small larvae, called **glochidia,** are produced. These glochidia are then expelled from the

mother and must find a fish in order to continue their existence. If a fish comes near, these larvae immediately clamp onto its skin or gills and live there as parasites until they have developed into small clams. These are commonly called "blackheads" when seen on fish. This seems to be an adaptation for distribution as well as for protection and nourishment. A fish may travel a great distance carrying these little parasites and they will drop off far from their place of origin. Since the clams are so sluggish in their movements this is probably the only way that they could be well distributed, especially upstream in a river.

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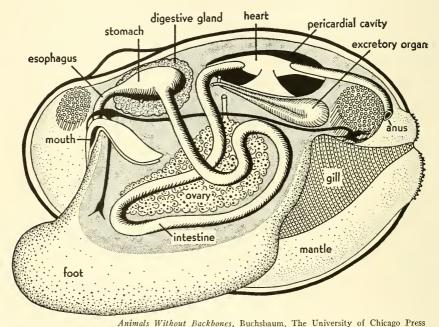
FIG. 19.5.   Internal organs of the clam. This diagram shows the digestive tract and various surrounding internal organs.

Certainly there is no one that has not heard of the renowned "clam bakes" and "clam chowder" of the New England states which testify to the good eating qualities of the marine clams. There are many varieties of edible clams in the ocean ranging from tiny ones no bigger than the end of your finger, which make delicious cocktails, to huge ones from which you can get a good sized steak. The New England long-necked clam buries itself in the sand of the beach when the tide is out and keeps just the tip of its neck above the sand. This neck is really an extension of the siphons. If a person comes too close and inquisitively looks down

to see just what this projection is, the clam may suddenly jerk the neck down and send a squirt of water into the eye of the curious person.

Oysters furnish us with a very important source of food and are cultivated in many places in order to supply the great demand for them. Oysters are not able to move about like the clams; the left side of the shell becomes attached to a solid object when the oyster is in the larval stage and there it remains for the remainder of its life. Since the foot is

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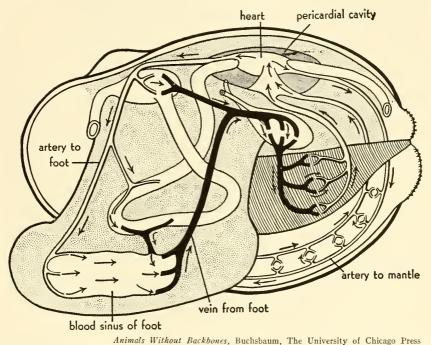
Fig. 19.6. Diagram of the circulatory system of the clam. Note the sinuses which make this an open system.

a locomotor organ, it is not needed by the oysters and hence it is not present. Otherwise the body structure is very similar to that of the clams.

Whenever a foreign body, such as a grain of sand or a small parasite, gets between the mantle and the shell of one of the bivalves, a layer of mother-of-pearl will be secreted around it to prevent injury to the soft body parts. Additional layers of mother-of-pearl will be formed around this as time goes on and at the end of several years a **pearl** will be formed. Pearls are commonly spherical in shape, but many odd shapes may be formed such as the pear-shaped or "tear drop" pearls that may be made

into beautiful earrings. The most valuable pearls are found in the pearl oyster which is a large oyster found in the West and South Pacific. "Pearl diving," however, is not such a desirable occupation for you will probably not find more than one pearl in a thousand oysters which may have been collected under hazardous conditions.
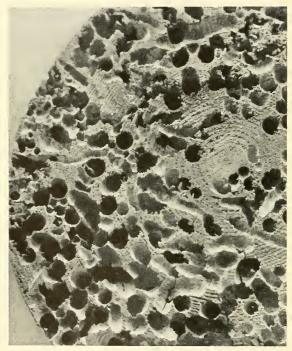
Photo by Winchester

Fig. 19.7. Damage done to wood by the ship worm in 12 months' time. This little bi-valved mollusk does great damage by boring through the wooden structure of ships and wharves.

In Toba, Japan, a man named Mikimoto discovered a method of artificially introducing foreign bodies between the mantle and the shell of the pearl oyster, thus stimulating pearl formation. About seven years are required for the formation of a pearl of commercial value, so returns on investment are somewhat slow, but certainly worthwhile when they come. Mr. Mikimoto has developed a great industry from his discovery and has become quite wealthy. He sometimes gives dinner parties at which he serves oysters in the shell. The luckier guests come away with one or more pearls as souvenirs of the occasion.

Class—Gastropoda

The foot may seem a rather peculiar place to find an animal's stomach; yet that is where it is in the Gastropoda, a name which means "stomach foot." However, the foot is about the biggest part of the body of an animal in this class and is able to contain the stomach without crowding. The **snail** is the best known example of this class. The bilateral symmetry of snails is somewhat disrupted since the visceral hump forms a spiral within the coiled shell. They creep along on the foot at the traditional "snail's pace" which averages about two inches a minute at full speed. However, their progress must be slow since they slide along in a layer of mucus which is secreted by a gland at the
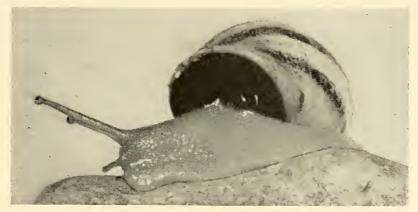
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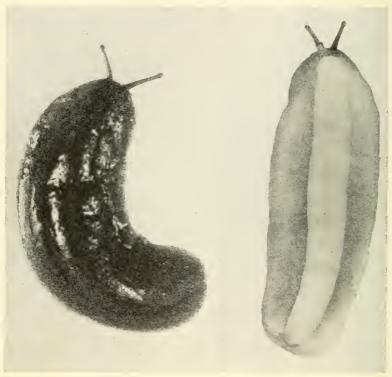
Fig. 19.8. A snail. Note the stalked eyes and the slimy appearance of the body.

anterior end of the foot. The progress of any animal would necessarily be slow if he had to spit and slide along as the snail does. The pathways of snails can be recognized by the silvery trails of dried mucus which they leave behind. The land snails usually do their traveling at night when the air is cool and moist. They withdraw their foot inside the shell and seal the opening with mucus during the day so that their bodies will not dry out.

The snail has its eyes on stalk-like tentacles which can be extended or retracted. These eyes do not see definite images as do human eyes, but are capable only of detecting relative light intensities.

A large species of snail is raised extensively in western Europe for food. They are considered a great delicacy in France and can even be purchased in some parts of the United States. There is no

reason why one should have an aversion to eating snails if he eats clams, since the organs of their bodies are basically similar.

Many of the aquatic snails are good scavengers. Such species are a great aid in balancing a fish bowl or aquarium since they eat remnants of food passed up by the fish and also eat the algae which otherwise might cover the glass. This effectively keeps down the growth of both bacteria and algae which often cause an aquarium to go foul.

Photos by Winchester

Fig. 19.9. A slug. In the dorsal view on the left note the resemblance to the snail except for the absence of an external shell. There is an internal rudiment of a shell, however. The long, creeping foot shows clearly in the ventral view of the animal crawling on a piece of glass at the right.

Some persons think the snails can crawl out of their shells and return to them because they sometimes see animals that look like snails without shells. These are the **slugs** which do not have noticeable shells as adults. However, a study of the embryonic development of the slug reveals that a shell is formed in the embryo just as it is in the snail, but fails to continue its development to a functional size.

There are quite a number of marine gastropods which can be recognized by the spiral shell. Many persons have a very interesting hobby of collecting these shells which are so abundant along the seashores all over the world. Smaller shells may be used for necklaces and bracelets as souvenirs for tourists, and the larger ones may be made into a variety of table ornaments of great interest and beauty.

Class—Cephalopoda

This class name means "head foot" because the foot is wrapped around the head, causing some confusion of the parts of each.

The **squid** is a good example of the class. The squid has a somewhat torpedo-shaped body, with the visceral hump drawn up into a long pointed shape and covered by the mantle, but not surrounded by a shell. There is a vestigial remnant of the shell, the **pen,** embedded in the mantle at the anterior edge, however, which serves to support the softer parts of the body. The foot bears ten **arms** that are lined with suckers which give the animal a good grip on anything around which it wraps these arms. The squid has two eyes that have the iris, lens, and retina, such as are found in vertebrate animals. This does not mean that the squids are very close relatives of the vertebrates, but because of the many other points of difference between the two, it is thought that the eye of the squid has developed independently along the same lines as the vertebrate eye.

The squid sucks water up into its mantle cavity for respiration and may use this same water for locomotion. There is a little tube leading from the cavity called the **siphon** which can expel this water rather forcibly and propel the animal in the opposite direction using the principles of jet propulsion. By pointing the siphon in different directions, the squid can control the direction of movement, aided somewhat by a pair of **fins** that project out to either side of the mantle. This method of locomotion causes them to move in a series of rapid darts when in a hurry, but they can use the arms to crawl along in a more leisurely fashion.

The squid not only has a pen, it also has ink, but these are not used for writing letters. There is an ink sac which opens into the mantle cavity and when in danger the squid will squirt a cloud of black ink out into the water which acts in the nature of an underwater "smoke screen," giving the squid an opportunity to escape. This is not always effective, however, for the squid is very commonly found in the stomach of fish and furnishes them with an important source of food. The squid is also an important source of food for man. They are eaten in the Orient, in

Italy, and can even be found on the menus of some restaurants in the United States.

An average-sized adult squid will be no more than a foot long, but there is a species of giant squid (*Architeuthis princeps*) which has the distinction of being the largest of the invertebrates. These squids have been found with a body length of about twenty feet and a total length, including their long arms, of fifty-two to fifty-five feet. In spite of this great size, they are preyed upon by a group of squid-eating whales. Apparently they put up a terrific battle, since many whales have been caught that had long stripes across their heads left by the suckers on the arms of the giant squids.
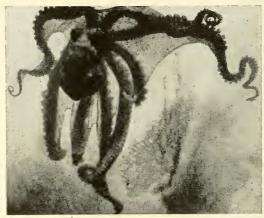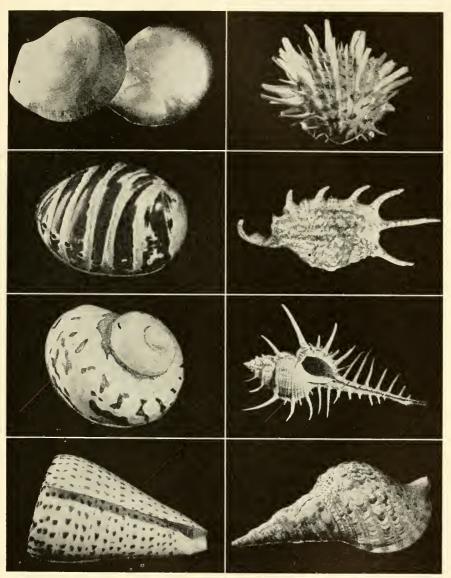
Photo by Winchester

Fig. 19.10. An octopus. Note the suction cups on the tentacles that enable this animal to attach itself firmly to solid objects.

(A graphic description of such a battle of titans is given by F. T. Bullen in *The Cruise of the Cachelot.*) Although he did not observe the end of the battle, the fact that he found the stomachs of numerous whales filled with large pieces of squids is ample evidence as to who were the victors.

During the days of the small sailing vessels, there were many sailors' tales of encounters with the giant squid. Some told of the huge animal wrapping its tentacles around a comparatively frail ship and pulling it under the water, after which it would grab the sailors in its deadly tentacles and crush them to death. These tales made good stories, but like many another sailor's yarn they were largely figments of a vivid imagination.

There is one species of squid called the **sepia** that produces a brownish colored ink and is an important source of this pigment for use in artists' paints. It is also called the cuttlefish and has a large pen, the cuttlebone,
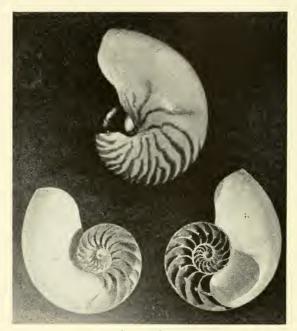
FIG. 19.11. Varieties of mollusk shells. Many strange and beautiful shapes and patterns of shells are produced by the mantle of different species of mollusks. Left to right and top to bottom these are: the pearl oyster, Avicula, collected near the coast of china; the thorny oyster, *Spondylus pictorum*, from the East Indies; the black abalone, *Haliotis cracheroidii*, from California; *Pterosera lambis*, from the East Indies; the Turk's cap, *Turba sarmaticus*, from Africa; *Mures scolopax*, from Japan; *Conus litteratus*, from Ceylon; and *Triton tritonis*, from the South Pacific.

which is removed and placed in the cages of captive birds, such as canaries, as a source of calcium.

One of the most feared creatures of the South Pacific is the giant **octopus,** or devil fish, that has been known, on rare occasions, to ensnare divers with its long snake-like tentacles. It does not compare with the giant squid in size, but some have been found with tentacles that could be spread in a radius of fifteen feet from a body as big as a washtub. The cold, wicked looking eyes; the soft, slimy body; and the long, wig-

Courtesy General Biological Supply House

Fɪɢ. 19.12.   Shells of the chambered nautilus. At top, a whole shell; at bottom, a shell that has been sawed open to show the chambers. The animal moves forward each season making a new and larger chamber.

gling tentacles combine to make this one of the most repulsive of all animals, yet the great majority of them are far too small to do man any bodily harm and they furnish us an important source of food. An average sized octopus will have a body no bigger than a grapefruit and, in the Mediterranean countries, South America, the South Pacific, and the Orient, boiled octopus is a much better known and more frequently eaten dish than our boiled lobster.

The octopus is very much like the squid in its body structure, but it does not have a pen for support and when taken out of the water its body

collapses like a mass of jelly. Also, it has only eight arms instead of ten.

The **chambered nautilus** is another member of the class Cephalopoda. Unlike the squid and octopus, its mantle secretes a shell, which is laid down in a series of spiral chambers to form a very beautiful, coiled shell. A new chamber is formed as the animal outgrows the older one, so each
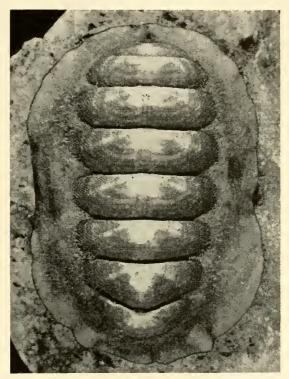
Photo by Winchester

FIG. 19.13. Chiton, a primitive mollusk. Note the row of articulating plates that take the place of less flexible shell as found in other mollusks.

new chamber is larger than the preceding one. Upon learning of the characteristics of this animal, Oliver Wendell Holmes wrote the well-known poem, "The Chambered Nautilus." The poem ends with a moral which is memorized by most grade school children:

> "Build thee more stately mansions, O my soul,
> As the swift seasons roll,
> _____."

Class—Amphineura

This class of mollusks seems to show a lesser degree of specialization than any other in the phylum and is, therefore, of interest in establishing possible relationships between this phylum and others. Members of this class have a ladder-like nervous system such as was found in planaria and a ciliated larva which is similar to that produced by *Neanthes*. Embryonic development of the flatworms, annelids, and Amphineura shows that the cells divide in the same way and form similar structures up to a certain point before beginning development in different directions. These facts would indicate a rather close relationship between these three phyla.

A typical genus is *Chiton* which crawls around among the rocks on the seashore eating the algae growing there. Its body looks like a broad flattened worm, but is covered on the dorsal surface with a series of eight plates which have articulating surfaces and give more freedom of movement than is found in other mollusks with a rigid shell.

Class—Scaphopoda

This is a minor class of marine mollusks that have a tubular shell open at both ends. Its members are commonly called toothshells because of the similarity of the shells to the teeth of some large animals.

Classification and Derivation of Scientific Words

Phylum Mollusca (L. *mollis,* soft; refers to the body parts).

Class A. Pelecypoda (Gr. *pelekys,* hatchet; *pous,* foot; refers to the shape of the foot). The bivalves, such as clams and oysters.

Class B. Gastropoda (Gr. *gaster,* stomach; *pous,* foot; the stomach is in the foot). Snails, slugs, conch, abalone, etc.

Class C. Cephalopoda (Gr. *kephale,* head; *pous,* foot; the foot is wrapped around the head). Squid, octopus, chambered nautilus.

Class D. Amphineura (Gr. *amphi,* both; *neuron,* nerve; there are two nerves running down the body). Chiton.

Class E. Scaphopoda (Gr. *skaphe,* boat; *pous,* foot; refers to the shape of the foot). The tooth-shells.

REVIEW QUESTIONS

1. Give the characteristics of the Mollusca.
2. What is the economic importance of the fresh-water clam?
3. How can you estimate the age of a clam?
4. Describe the feeding habits of a clam.

5. What provision is made for distribution of young clams?
6. Why does the oyster have no foot?
7. Tell how pearls are produced.
8. Describe locomotion in the snail.
9. What is the significance of the embryonic shell in the slug?
10. What is the purpose of the pen and ink of the squid?
11. How does the octopus differ from the squid?
12. Why is Chiton of importance in a study of the Mollusca?
13. How is water drawn into the siphon of a clam?
14. Name the mollusks that are important sources of human food.
15. How is pearl formation stimulated artificially?
16. Describe the arrangement of the shell of the chambered nautilus.
17. What is the significance of the similar embryos of Planaria, Neanthes, and Chiton?

20

Animals with Spiny Skins — The Echinoderms

This phylum name, *Echinodermata*, means spiny skin; and, if you have seen a starfish, or perhaps stepped on a sea urchin at the seashore, you will realize that the name is a very appropriate one. Most members of this phylum have a skin which has become calcified and, therefore, is quite hard and brittle with numerous spines which are protective in nature. They are all marine and, as a result, not well known to those not living near coastal regions. They are very abundant in salt water, especially in tropical waters.

The echinoderms at first glance are difficult to fit into an orderly series of invertebrate phyla. In each of the previous phyla, with the possible exception of the mollusks, the typical animal selected for study possesses just about everything that the preceding one had, plus some additional characteristics that make it a more advanced type of animal. The echinoderms are fairly advanced in some systems, but in others they seem more like some of the simplest metazoans, especially the coelenterates. In still other systems they are neither primitive nor advanced, but specialized in ways that are peculiar to themselves. However, when their embryology is studied critically, we find many characteristics which are more like those of the chordates than any of the invertebrate phyla. For example, they form their three germ layers and their coelom in almost exactly the same way as *Amphioxus*, which is a primitive chordate animal. This is of particular significance because many studies have shown that embryonic characteristics are usually more reliable than adult characteristics in determining animal relationships. Adults often become so highly specialized in adaptations to varying environments that they may show little resemblance to the adults of rather close relatives which may have become specialized along other lines. The embryos, however, tend to start development in somewhat the same manner as they did before the adults become so specialized. Hence, when we find two animals with a very similar method of embryonic development we may assume that these two animals are rather closely related, even though they may show considerable morphological difference as adults. Because of the similarities in the embryonic development of the echinoderms and the primitive chordates,

there has been formulated a theory of the echinoderm ancestry of the chordates. This theory is quite plausible in spite of the great diversity in the adults of these two phyla.

A word of caution about the reliability of embryos as a means of establishing animal relationships should be introduced. In 1828, the great German embryologist, Von Baer, brought forth his observations on the similarities among the embryos of different animals. He emphasized the point that the embryo of one animal would resemble the embryo of a closely related animal as we have pointed out. Less scientific workers, such as Ernst Haeckel, seized upon this idea and formulated a "theory of recapitulation" which received wide acceptance for a time. This theory holds that an embryo tends to retrace all the changes which have occurred in the ancestry of the animal. As this theory has been subjected to careful scientific analysis, it has become apparent that this is not true. There are a few similarities in the developing embryos of higher animals and the adults of some more primitive forms, but it is now believed that these are incidental to the development of the embryo and not a recapitulation. The embryo tends only to reproduce those embryonic characteristics which it had in the past as an embryo and not the characteristics of the past adult forms. Thus, comparative embryological studies are of great importance in establishing animal relationships, but not in showing the changes undergone by the adults in their evolutionary development.

The Starfish—Asteroidea

The common starfish, *Asterias,* is neither star-shaped nor is it a fish, but it was given this name when it was thought that stars had five points and when every animal which lived in the water was a fish. We now know that stars are spherical in shape and that fish are only one type of many of the living inhabitants of our ponds, lakes, rivers, and seas; but the name, starfish, is still used for this interesting echinoderm.

When a starfish is examined it will be noticed that it has **radial** rather than bilateral symmetry. This might lead to the conclusion that this is a rather primitive animal, about on the level with the coelenterates; yet, as we study its various systems, it becomes evident that it is much more highly organized than the coelenterates. Some clue to this unusual combination of characteristics is found in the larva of the starfish—the larva is **bilateral** in symmetry. Since, as we have just learned, the larva tends to continue developing in the same way after the adult has become different through specialization, we may conclude that this animal was probably bilateral as an adult at some time in its past history.

The starfish is well protected by a **skeletal system.** The outer surface of the body is covered by skin through which hard knobs of lime protrude to form **spines.** This gives excellent protection and support for the soft body parts within the body. At the same time the arms are quite flexible because of the soft skin between the spines which allows the arms to bend easily. There are small pinchers, the **pedicellariae,** which come out from around the base of the spines. These pinchers keep off foreign matter that might adhere to the body of the starfish and interfere with respiration and other life processes.
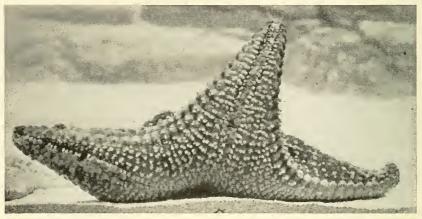
Fɪɢ. 20.1.   A starfish in an aquarium.   Note the suction cup appearance of the ends of the tube feet where they are attached to the glass.

In the living starfish there are delicate little finger-like projections coming out from the skin between the spines.

These projections are extensions of the body cavity, or **coelom,** which contains the coelomic fluid. They are called **skin gills** and absorb oxygen from the water and return the carbon dioxide to it in **respiration.** The coelomic fluid circulates all over the body and takes care of **circulation,** but there are no well-organized vessels as there were in the earthworm. The skin gills also aid in **excretion.** The coelomic fluid contains amoeboid cells which engulf the excretory wastes which diffuse out into this fluid from the body. Eventually, these cells become filled with the waste and squeeze their way out of the body through the skin gills, carrying themselves and the waste out into the water never to return.

The starfish has a **muscular system** which enables it to move the arms, to pinch with the pedicellaria, and to make certain other simple move-

ments. However, the major movements are accomplished by an entirely new system that is found in no other phylum of animals. This is the **water vascular system** which uses sea water under a sort of internal hydraulic pressure to accomplish its objectives. On the aboral surface of the central disc of the starfish is a hard round structure called the **madreporite** which is the beginning of this system. The madreporite admits the proper amount of sea water into the system. A little calcified canal, called the **stone canal,** leads from the madreporite to the **ring canal,** from which a **radial canal** radiates out into each of the five arms. Alongside the radial canals are little **ampullae** which connect to **tube feet** which can
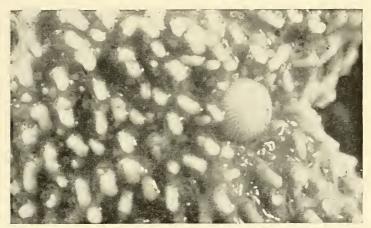
Fig. 20.2.   Close-up of the central disc of a starfish. Note the round madreporite, the numerous spines, and the small pedicellariae at the base of the spines.

be extended through the oral surface of the body. These can be seen externally lying in rows in the **ambulacral grooves** of each arm. To extend a tube foot the starfish squeezes the connecting ampulla. This forces the sea water out into the tube foot and makes it much longer than it was previously. On the bottom of the tube foot, in most starfish, is a little suction cup which may be attached to some solid object. Once this attachment is made the muscular wall of the tube foot may contract, thus forcing the excess water back into the ampulla. This contraction of the tube foot will pull the starfish toward the point of attachment. Through cooperative action of many tube feet the animal draws itself along in a rather slow and awkward fashion. Because the tube feet cannot get a grip on sand, starfish are seldom found along shores with a sandy bottom, but are very abundant where the shore line is rocky.

The starfish has one of the most interesting methods of **digestion** found in the animal kingdom. Its food consists almost completely of mollusks which have hard protective shells around their bodies. If you have ever tried to pry open the shell of a clam or oyster you may wonder how such a small and clumsy animal as a starfish could possibly feed on these mollusks. The starfish, however, can open these shells with comparative ease through a principle of applied physiology. As an illustration, we will say that it finds an oyster that it wishes to eat. It will settle
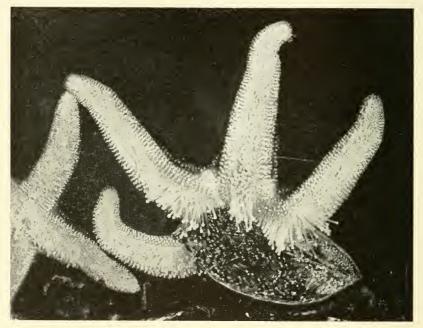
Photo by W. K. Fisher

FIG. 20.3. A starfish opening a clam. The starfish has attached its tube feet to the shell of the clam and, through continued pulling, will eventually open it so that the soft parts inside may be devoured.

itself down over the portion of the shell that opens and spread its arms down on either side of the shell and attach the tube feet by suction and begin to pull. The oyster has very powerful muscles which close the shell and it would appear rather secure against the slight pull which the starfish is able to exert. However, the starfish is a patient animal so it continues pulling and when one arm gets tired it will rest it while pulling with another. It is a well-known principle of muscle physiology that continuous contraction cannot be maintained for a very long period of time, and so it is only a few minutes before the muscles of the oyster

must relax and the shell opens. Then the starfish does a very strange thing; it everts its stomach through its mouth and wraps it around the soft body parts of the oyster and pours out powerful digestive juices that digest the oyster right in its shell. The digested oyster is absorbed partly through the stomach wall and partly by the pyloric caeca and the liquefied food passes into the coelomic fluid by which it is distributed. Retractor muscles extending from each arm to the stomach pull it back into place and the animal is then ready to seek another meal. A single starfish may destroy ten or twelve oysters a day in this way and, needless to say, starfish are great enemies of the oyster fishermen. Various steps are taken to combat their presence in oyster beds; one common method is to drag the ends of frayed rope or similar structure over the bottom. The starfish will grasp these objects with their pedicellariae and are thus lifted to the surface. At one time they were chopped in two and thrown back in the water, but, because of regeneration, this actually doubled the population. Now they are collected and dried so that death is certain.

There are many tiny mollusks which may also serve as food; these are taken into the stomach through the mouth and, after digestion, the shells are spit out through the mouth.

The anus of the starfish is used very little, since for the most part only digested or easily digested particles are taken into the digestive system. When small mollusks are ingested, their shells are more easily discharged through the mouth on the underside. The ancestors of the starfish, in all probability, had a functional anus; and, although still present, it is so greatly reduced in size that it is regarded as a vestige. The secretion of a plentiful supply of digestive fluids reduces the time that a starfish has to sit on an oyster with its stomach protruding. This is accomplished by five large pairs of pyloric caeca that fill the coelom of each of the five arms.

The nervous system includes a nerve ring around the mouth and a nerve running out into each arm with smaller branches connecting with the different parts of the body. Sense organs are poorly developed, but at the end of each arm there is a pigmented eyespot which is sensitive to light and both the skin gills and pedicellariae are sensitive to tactile stimuli.

Reproduction is quite simple; sexes are separate and a pair of **ovaries** or **testes** lies in each arm between the pyloric caeca and the ampullae. Their size varies considerably with the degree of maturity of the animal and the season of the year when they are gathered. These gonads open to the outside by small pores at the points on the central disc between the arms. Sperms and eggs are shed into the water during the reproduc-

tive season and the sperms find the eggs and fertilize them. A little bi-
laterally symmetrical larva soon develops. Bands of cilia around it
enable it to swim freely in the water, and this aids in distribution. The
adult starfish is so sluggish that it does not get very far during its life-
time and if all its offspring grew up in the same spot conditions would
very likely be quite crowded, but this free-swimming larva can travel to
new locations and thus avoid the congestion.

Regeneration of the starfish is rather extensive. A single arm, as
long as it contains a portion of the central disc attached to it, can regen-
erate all the missing parts. Another interesting process called **autotomy**
is illustrated by the starfish. If a portion of an arm is crushed, the
entire arm may be automatically severed from the body near the central
disc and a new arm regenerated.
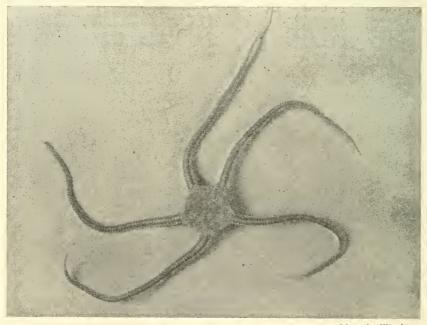
Photo by Winchester

FIG. 20.4.   The brittle star.

Brittle Stars—Ophiuroidea

This class includes forms that rather closely resemble the starfish, but
generally are called **brittle stars** because their arms come off so easily.
If you merely grasp one of the arms with your fingers it is very likely
that the animal will cut off the arm by autotomy and crawl away and re-

generate a new one. Brittle stars are not so aggressive in their feeding habits as the starfish and are usually content to crawl around and eat mud on the sea bottom, deriving their nourishment from whatever organic matter the mud might contain.

Sea Urchins and Sand Dollars—Echinoidea

This class includes the **sea urchins** and **sand dollars**. The sea urchins are globe-shaped echinoderms with very long spines projecting out from their bodies which are a very effective protection. Some species of these have poison on their spines, so it pays to be careful where you wade in
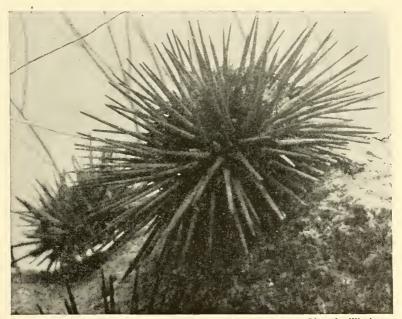
Photo by Winchester

FIG. 20.5. A living sea urchin. The long, sharp spines afford a very good protection to this echinoderm.

regions where these may be found. When the brittle skeleton is cracked the yellow gonads may be seen almost filling the interior, and these are sometimes used as food. They are especially popular in regions around the Mediterranean Sea and are even sold in large quantities from the push carts of the lower east side district of New York around Christmas time each year. Many of the customers are probably emigrants from the Mediterranean countries who developed the taste before coming to the United States.

The sand dollars are little disc-shaped echinoderms that have a traditional star-shape outlined on both the oral and aboral surfaces. A dried one lying on the sand on the beach could be mistaken at a distance for a silver dollar.

Sea Cucumbers—Holothurioidea

These are the sea cucumbers which are found along the bottom of the sea in shallow water in tropical regions. They do resemble the cucumber in appearance and differ from the other members of this phylum in
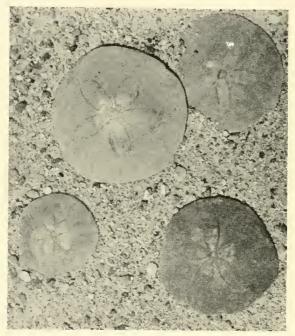
Photo by Winchester

FIG. 20.6. Sand dollars. These disc-shaped echinoderms are often washed up on the sand of the beach.

having a flexible outer skin that feels more like a piece of soft leather than the hard spiny skin of the starfish. A number of tentacles come out around the mouth which are waved in the water until sufficient food particles adhere to them; then they are turned down into the mouth, the mouth is closed, and the tentacles are withdrawn sucking the food off, very much like a child would stick his fingers in a can of molasses and then suck them. In oriental countries they are in great demand for soup making, and a great industry in the Philippines consists of collecting and

drying the sea cucumber for shipment to China and other far eastern countries for this purpose. When sold for human consumption they are called beche-de-mer (worm of the sea). Most of us would probably be more likely to eat them if they were called sea cucumbers.

They have a very interesting method of protecting themselves from enemies. Since their skin is not hard like that of the other echinoderms they are more liable to injury, but have adopted another method of protection that is very effective. Inside the body is an extensively branched respiratory tree which helps to remove oxygen from water which is sucked into the anus for this purpose. When attacked by an aggressive

Photo by Winchester
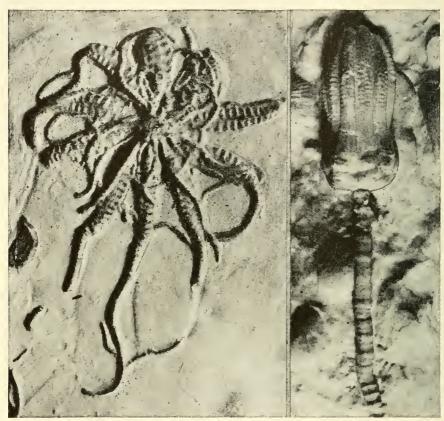
Fig. 20.7. A sea cucumber. The resemblance to the familiar vegetable from which it gets its name is quite evident in this photograph. The small structures coming out of the body are tube feet.

enemy, such as a large crab, these respiratory organs may be thrown out through the anus forming a tangled mass of threads which ensnares the crab's legs and pinchers while the sea cucumber leisurely crawls away and regenerates another set of organs.

Sea Lilies—Crinoidea

The name of this class means lily-like and members of this class are commonly called the sea lilies. Most of the animals in this class have a stalk which is attached to a rock or similar underwater structure and five arms with branches coming out around the mouth. The sea lilies are very abundant animals, but not as well known as the other echinoderms because many of them inhabit the deep regions of the seas where human beings cannot venture except with specially built devices that can withstand the great pressure of the water. In these

FIG. 20.8. Fossilized sea lilies. These specimens were found far from present-day oceans, thus indicating the presence of ancient seas in these regions.

deep, dark recesses of the ocean, where the pressure is so great that a person would instantly be crushed into an unrecognizable pulp if he were placed there, these animals carry on their existence generation after generation. Their abundance in such regions in the past is shown in fossil deposits, especially those of a limestone nature. These fossils are frequently found far inland and are an indication of the evolution of the earth's surface for their presence indicates that these areas were at one time at the bottom of a deep sea.

Classification and Derivation of Scientific Words

Phylum Echinodermata (Gr. *echinos,* spiny; *derma,* skin).

    Class A. Asteroidea (Gr. *aster,* star; *eidos,* like). The starfish.

        Genus 1. Asterias (Gr. *aster,* star).

Class B.   Ophiuroidea (Gr. *ophis,* snake; *oura,* tail; *eidos,* like; their arms resemble snake tails).   The brittle stars.

Class C.   Echinoidea (Gr. *echinos,* spiny; *eidos,* like).   The sea urchins and sand dollars.

Class D.   Holothurioidea (Gr. *holothurion,* sea cucumber; *eidos,* like).   The sea cucumbers.

Class E.   Crinoidea (Gr. *crinon,* lily; *eidos,* like).   The sea lilies.

REVIEW QUESTIONS

1.   Why are the echinoderms considered more closely related to the chordates than to any invertebrate phyla?

2.   Why is the larva of the starfish of particular significance?

3.   What are pedicellariae and what is their function?

4.   Describe respiration, circulation, and excretion in the starfish.

5.   Explain how tube feet are extended and retracted.

6.   Describe the feeding habits of the starfish.

7.   What is meant by autotomy?

8.   Why do oyster fishermen no longer chop up starfish and throw them back in the water?

9.   Why has the retention of a bilateral, free-swimming larva been of survival value to the starfish?

10.   Has the development of radial symmetry in the adult been of any value to the starfish?   If so what?

11.   What unusual method does the sea cucumber have of defending itself?

12.   Why are sea lilies more commonly seen as fossils than as living animals?

13.   In general, organs which are not used tend to deteriorate in the species to the point where they become nonfunctional.   In what way is this principle illustrated in the starfish?

21

Climax of the Animal Kingdom— Phylum Chordata

This last phylum of the animal kingdom includes the largest and most conspicuous animals of the kingdom and is, therefore, the best known as a group. This, together with the fact that the phylum includes man, generally causes us to think of it as the most important group of animals. The term vertebrates is almost synonymous with chordates because the great majority of the chordates are vertebrate animals.

Chordate Characteristics

The chordates include such a variety of animals that it would seem rather difficult to list generalized characteristics that apply to all. This phylum includes such animals as elephants, fish, snakes, and birds and, at first glance, such an assortment would seem to have very little in common. However, there are certain morphological features that all possess.

A Dorsal Tubular Nerve Cord. The nerve cord runs the length of the body against the dorsal body wall in contrast to the ventral nerve cord found in the higher invertebrates. Embryologically this cord is formed from a strip of ectoderm lying on the dorsal surface of the embryo. This strip first sinks inward to form a groove and then the upper walls of the groove come together and fuse, forming the tube. The anterior part of the tube enlarges to form the brain, whereas the remainder forms the spinal cord which retains its tubelike characteristics throughout the life of the animal.

A Notochord. Just under the spinal cord is a flexible tube-like body which is called the notochord. The phylum name is taken from this characteristic. In the higher chordates the notochord is present in the embryo only, since it is replaced by the bony vertebral column in the adult form. In the center of each intervertebral disc of man, however, there is a vestige of the notochord which helps to make this disc more resilient.

A Post-anal Tail. A part of the body, containing the notochord or vertebral column, projects beyond the anus to form a tail at some time
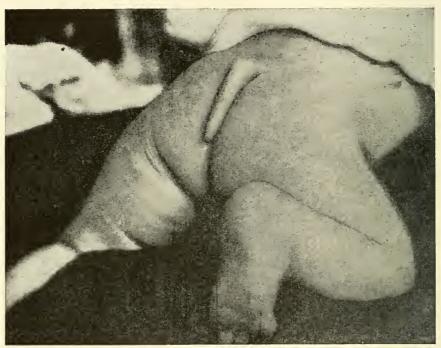
during the animal's life.   The last part of the statement is necessary because there are a few chordates that have dispensed with their tails in the adult stage.   These include frogs, guinea pigs, apes, and man.   Yet, all of these, including man, have tails in their early development, but they

Photo by C. F. Reather, Carnegie Inst. of Washington, Dept. of Interior

Fig. 21.1.   A human embryo about 32 days of age showing the gill clefts and tail. These are chordate characteristics shown by all chordates in their early embryonic life and which persist into the adult life of the lower chordates.   Note the limb buds, not yet differentiated into fingers and toes; the heart region which must be very large to accommodate the comparatively large heart; the muscle segments down the back; and the umbilical cord.

fail to develop in proportion to the rest of the body and are rudimentary in the adult animals.   Man has a tail bone, consisting of several small vertebrae fused together, as a remnant of his embryonic tail.   Occasion-

ally a baby is born with a definite tail when this rudimentary structure develops too far, but this is generally quietly and inconspicuously removed so that there are few that know that it ever happened.   There is no such post-anal tail among invertebrates since the anus normally is found near the posterior tip of the body.

FIG. 21.2.   A baby with a tail.   All persons have tails as embryos and quite a number of babies are born with tails like this Portuguese infant.   However, these can easily be removed surgically so that few ever know of these cases.

Pharyngeal Gill Clefts.   The external pharyngeal region of all embryonic chordates bears a series of gill clefts.   In those forms that develop gills for respiration, these clefts extend inward and perforate the pharynx to produce gill slits with both internal and external openings. In those that use lungs for respiration, either the clefts never completely penetrate the pharynx and form no gill slits or, if the slits are formed, they become closed during embryological development.

Blood Flows in a Posterior Direction in the Dorsal Vessel.   As the blood is pumped over the body, it flows backward along the dorsal wall just under the notochord or vertebral column in a vessel called

the dorsal aorta to supply the parts of the body posterior to the heart. In the ventral aorta it is pumped forward. This is just the reverse of the directions of blood flow in the higher invertebrates. In chordates the blood remains at all times within vessels, and therefore they have a closed type of system like the Annelida rather than an open type of system such as is found in the Arthropoda.

An Endoskeleton. The skeleton of the chordates, when present, is internal to some of the muscles and other body structures and, therefore, is called an endoskeleton. The advantages and disadvantages of this
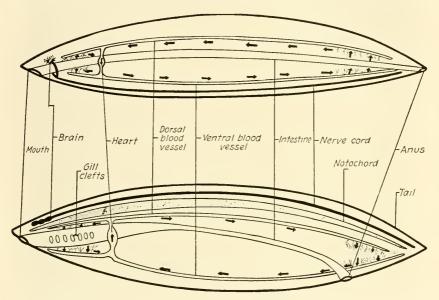
FIG. 21.3. Diagrammatic comparison of a higher invertebrate with a lower vertebrate animal. Note, in the invertebrate, the nerve cord is ventral and the blood flows anteriorly in the dorsal vessel. In the vertebrate the nerve cord is dorsal, the blood flows posteriorly in the dorsal vessel, there is a notocord, there are gill clefts in the pharyngeal region, and there is a tail beyond the anus.

type of skeleton have been discussed in Chapter 13 in comparison with the exoskeleton of some of the higher invertebrates. Some vertebrates have developed a type of exoskeleton in addition to their endoskeleton. The turtle is quite well protected by an enlargement and fusion of scales to form its "shell."

Subphyla of Chordates

The phylum Chordata is divided into four subphyla. The first three of these are small and little known and are ordinarily not considered in

detail in a general course in zoology, but they are listed here in order that our survey of the animal kingdom will be complete.

Subphylum 1. **Hemichordata.** A typical representative of this group is the acorn worm, *Balanoglossus*. This is a primitive, worm-like,
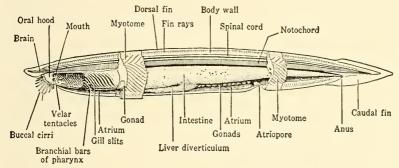
FIG. 21.4. A sea squirt, tunicate. This primitive chordate is little more than a bag with siphons for sucking in and squirting out the water in which it lives. However, its larva has typical chordate characteristics.

burrowing animal. At the anterior end of the body there is an egg-shaped proboscis which fits into a collar which is immediately posterior. This gives the anterior end of the body an appearance somewhat like an acorn

in its cup.   The rest of the body, the trunk, is long, slender, and somewhat flattened.   The trunk bears numerous gill slits on its anterior end up near the collar.   The collar, which really corresponds to the head, contains the mouth and a primitive brain.   Behind the brain is a nerve cord, which is somewhat tubular in structure, but there is some question as to whether it should be considered a true tubular nerve cord.   A short strand of cells extends from the collar into the proboscis.   This group of cells forms what is usually called a notochord, but, because it does not extend posteriorly under the nerve cord, this is also open to question.   The larva of the acorn worm is of significance because it is so similar to some larvae of the echinoderms.   Before the metamorphosis of this (tornaria) larva was observed, it was thought to be an echinoderm.

Foundations of Biology, Woodruff, The Macmillan Company

FIG. 21.5.   Amphioxus, with part of the body wall removed to show the internal organs.

This strengthens the theory of a connecting link in the ancestry of the chordates and the echinoderms.

Subphylum II.   **Urochorda.**   This group includes the sea squirts or tunicates which are not much more than flexible little bags attached at one end and sucking water in and squirting it out at the other end.   They do not seem to have much in common with the other members of the phylum, but their larvae are free-swimming forms and have a notochord in the proper relation to the dorsal nerve cord and several other chordate characteristics.

Subphylum III.   **Cephalochorda.**   The most important genus of this group is Amphioxus, a little marine animal that is found near the shore line of sandy beaches in certain tropical regions of the world.   It is an excellent specimen for advanced study in working out the beginnings of vertebrate characteristics and is an animal with which all students of comparative vertebrate anatomy soon become thoroughly familiar. Amphioxus is shaped somewhat like a small, slender fish.   It has two

longitudinal folds of skin (metapleural folds) extending most of the length of the body, and it is thought that these may be forerunners of paired appendages. It also has median dorsal and caudal fins. The notochord runs from one end of the body to the other and gives a certain degree of rigidity to the body. The muscles are V-shaped segments known as myotomes which extend the entire length of the body. The hollow spinal cord lies just above the notochord, but the brain is very poorly developed and actually contains less nerve cells than an equivalent portion of the spinal cord. There are no definite eyes, but a row of pigment spots along the spinal cord are sensitive to light.

Amphioxus often lies half buried in the sand with only the oral hood protruding. Buccal cirri line the oral hood and prevent sand from entering the body. Water is drawn through the oral hood and passes through the mouth into the pharynx due to the action of cilia. The water then passes out of the pharynx through numerous gill slits into the atrium, a cavity which surrounds the pharynx, and finally flows back through the atriopore, which is an opening that might be compared to the excurrent siphon of the clam. Particles of food in the water are caught in a sticky mucus in a groove, known as the endostyle which lies on the ventral border of the pharynx. From here the food is carried back into the intestine where it is digested with the aid of the liver diverticulum, a ventral outgrowth from the intestine.

Sexes are separate, and gametes are produced by 26 pairs of gonads which are found in the atrium. Amphioxus is most like the vertebrates of all the chordates, but since it does not have even the rudiments of a vertebral column, it must rely upon the notochord for support of its muscles.

Subphylum IV. **Vertebrata.** This group includes the remainder of the chordates. They take their name from the vertebral column which consists of bony articulating vertebrae surrounding the spinal cord, which is found in all but the most primitive vertebrates.

Classification and Derivation of Scientific Words

Phylum Chordata (G. *chorde,* cord; refers to the notochord that is characteristic of this group).

Subphylum I. Hemichorda (Gr. *hemi,* half; *chorde,* cord; have a notochord only in the anterior end of the body). Example, acorn worms.

Subphylum II. Urochorda (Gr. *oura,* tail; *chorde,* cord; larvae have a notochord in the tail). Example, sea squirts.

Subphylum III.   Cephalochorda (Gr. *kephale,* head; *chorde,* cord; the notochord extends forward into the head).   Example, Amphioxus.

Subphylum IV.   Vertebrata (L. *vertebratus,* jointed; refers to the jointed condition of the vertebrae).   Example, frog.

REVIEW QUESTIONS

1.   Tell how the chordate nerve cord gets its tubular shape in embryonic development.

2.   What is a notochord and where is it found?

3.   Why do we say that a post-anal tail is a chordate characteristic when there are important members of this phylum, such as man, that do not have a tail?

4.   Why is a study of the embryo of great importance in the classification of the chordates?

5.   Compare the chordates with higher invertebrates with respect to blood circulation.

6.   Why are the sea squirts placed in the chordates?

7.   In what ways is Amphioxus like a true vertebrate?

8.   What fundamental difference is there between Amphioxus and a true vertebrate?

9.   Compare the structure and position of skeletons in vertebrates and invertebrates.

10.   Name some vertebrates with well developed exoskeletons.

11.   Why is the term Vertebrata almost synonymous with Chordata?

22

The Vertebrate Body

Support, Protection, Movement, and Coordination in the Frog and Man

As we have studied the animal kingdom, we have chosen a type animal from each phylum to illustrate the characteristics of that phylum. This has not been a difficult task, since in every phylum there has been one that was somewhat representative of the entire group. The task is much harder for the chordates, however, because of the great diversity of animals that are included. By popular accord of competent zoologists the frog seems to be the animal chosen for this purpose. It lies between the lowest and the highest of the group, it is both a land and water animal, and it is common and easily obtained for laboratory study. Therefore, we will survey the systems of the frog as a representative of this important phylum of animals. However, since man is also in this phylum and we are particularly interested in this species of animal, we will include discussions of the human body along with the study of the frog. Superficially, the frog would not appear to have much in common with man, but the general plan of body organization is the same and much that is said about the frog will also apply to man. Therefore, it will be rather easy to gain some insight into the life processes of the human body by comparison with those found in the frog. The important differences between the two will be pointed out at the end of the discussion of each of the systems.

The Skeletal System. The general functions of the skeletal system are **support, protection,** and **muscle attachment.** The skeleton of the frog is composed largely of bone and does a very good job of supporting the softer parts of the body. There is a case of bone around the brain and spinal cord, so these vital organs are protected, but there is very little protection of the rest of the body. The large voluntary muscles of the body need some solid attachment in order to function, and the bones serve this purpose.

Since the bones are not very flexible there must be numerous **movable joints** between them to allow for body movements. However, body movements would be very noisy and there would be a lot of friction if the edges of the raw bone ground against one another at the joints. This

does not occur because the ends of the bones are padded with **cartilage** at the joints and there is a lubricating liquid, the **synovial fluid,** that further reduces friction. If a person receives an injury to the knee joint this fluid may leak out and cause a swelling under the skin called "water on the knee." The bones must also be held in place at a joint and there are tough membranes, called **ligaments,** that run from one bone to the other to hold them together.

There are also many **immovable joints** where the bones come together in such a way that there is little or no movement possible. There is no joint cavity and no synovial fluid. Such joints are found between the

Photo by Winchester

FIG. 22.1. Leopard frog. Note the tympanic membrane just posterior and ventral to the eye and the prominent sacral hump on the back.

bones of the skull which meet along jagged, saw-toothed lines called sutures. Such joints allow growth of the bones during development of the brain. They also allow some movement of the bones of the skull during childbirth. In mature adults many of these sutures become fused together and growth in size of the skull ceases.

The skeleton of the frog may be divided into the following parts:

I. The axial skeleton.

    A. The skull. Composed of numerous bones, all of which are immovably fused together except the lower jaw which has a movable joint enabling the frog to open its mouth.

       1. Brain case.

       2. Auditory capsules.
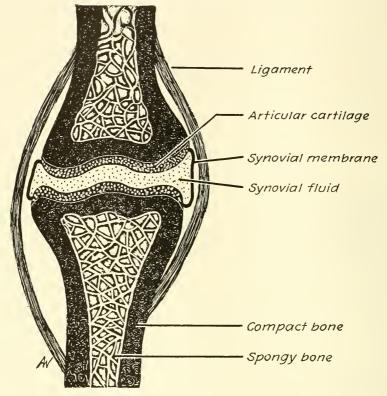
Fig. 22.2.   Londitudinal section through a typical hinge joint such as is found at the elbow.

        3. Upper jaw bones.
        4. Lower jaw bones.
        5. Teeth.
   B. The spinal column.
        1. Vertebrae (including the urostyle which is formed by a fusion of vertebrae that usually form the tail bones).
   C. Sternum.

  II. The appendicular skeleton.
    A. Anterior portion.
        1. Pectoral girdle.
        2. Bones of foreleg.
    B. Posterior portion.
        1. Pelvic girdle.
        2. Bones of hind leg.
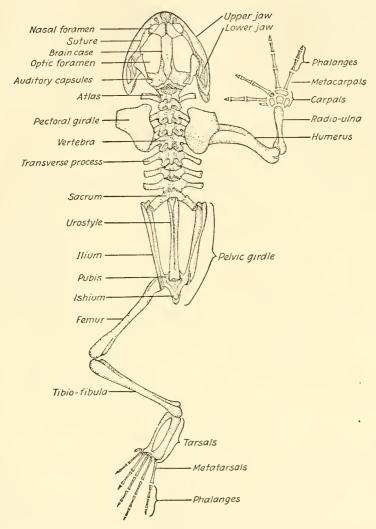
FIG. 22.3. Dorsal view of the skeleton of the frog. The hind leg has been somewhat shortened in proportion to the rest of the body.

Although the human skeleton is considerably more complex than that of the frog, it is built on the same fundamental plan. Even when a bone found in the frog appears to be missing in the human skeleton, a study of young human skeletons will usually reveal it. The brain case in man is tremendously enlarged to make room for our highly developed brain. The relative size and shape of many of our skull bones

have been modified in this change, but actually the same bones can be identified in most instances. We have only one bone in our lower jaw as compared to three pairs of bones in the jaw of the frog, and we have three ear bones in each ear as compared to one in the frog. Careful studies have shown that the two extra ear bones in man have been derived from two bones in the corners of the jaws of the frog. The bones are still there; they have merely changed their functions and positions. Man has seven cervical vertebrae in the neck instead of one as in the frog. The frog has seven trunk vertebrae with long transverse proc-
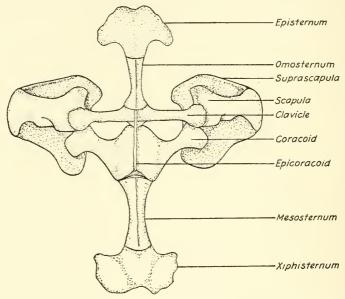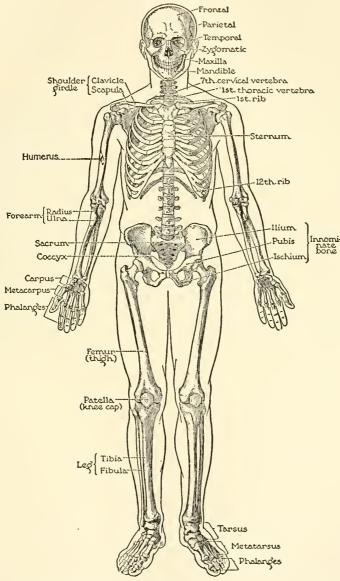
FIG. 22.4. Ventral view of the sternum and pectoral girdle from the frog skeleton.

esses. In man the trunk vertebrae are divided into two kinds, the thoracic vertebrae which bear ribs, and the lumbar vertebrae which have long transverse processes as in the frog. The twelve pairs of ribs of man encircle the thorax, and most of them are attached to the sternum, creating the thoracic basket which holds the lungs and heart. In the pelvic region there are five vertebrae fused to form the sacrum instead of a single sacral vertebra as in the frog. Man also has a vestige of the tail called the coccyx which corresponds to the urostyle in the frog.

The pectoral girdle in man lacks a coracoid bone, but a vestige of this bone is present in a child. It eventually fuses to the scapula, forming the coracoid process. The radius and ulna are separate bones in man allowing us to turn the hand freely, a movement which is indis-

pensable in the use of tools and other implements. Incidentally, this movement is also necessary in swinging from trees, an activity that may have preceded the use of tools.

Human Physiology and Anatomy, 3rd Ed., Millard and King, W. B. Saunders Co.

FIG. 22.5. Anterior view of the human skeleton.

The pelvic girdle and legs of man are very similar to those of the frog except that the tibia and fibula which are fused in the frog are separate in man. The development of the heel in the foot is an important factor in enabling man to maintain an erect position. There is a powerful tendon, the tendon of Achilles, which holds the foot flat and prevents us from falling forward. Savage races sometimes cut this on their captives to prevent them from escaping. The tendon received its name from the story that the mother of Achilles held her son by this region when she immersed him in the river Styx.
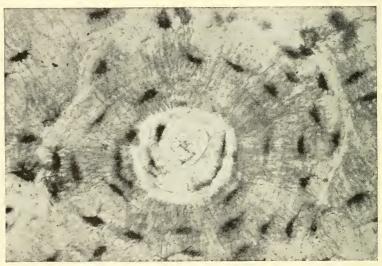
Photo by Winchester

Fig. 22.6. Photomicrograph of thin section of compact bone from the femur. Note the Haversian canal as a large circle and the small lacunae arranged concentrically around the canal. The small processes extending out from the lacunae are the canaliculi.

In spite of popular opinion, bones are not immutable structures, but are actually very plastic—their parts are constantly being torn down and replaced from within. Many primitive races change the shape of the heads of their children by binding them. Damage to the nerve cells in the spinal cord by poliomyelitis will result in small, weak bones on the side of the body afflicted, while extensive use of an arm or leg on one side will result in larger bones on that side.

The Muscular System. Since the muscular system is so closely related to the skeletal system it is logical to study this system next. Muscle cells are highly specialized tissues that do only one thing; that is, they make themselves shorter, or contract, upon stimulation. It is by

means of this simple reaction that all of the complicated movements of an animal's body are performed. There are three kinds of muscles, which are somewhat different in their reactions, so they will be studied separately.

The first of these is the **striated** or **skeletal** type of muscle. They are called striated muscles because, when viewed under the microscope, they are seen to be composed of many long cylindrical fibers bearing small cross striations. They are called **skeletal muscles** because they are nearly all attached to some part of the skeleton. The movements which take place at the movable joints are controlled by such muscles which pass freely over the joints, but are attached to the bones on either side.
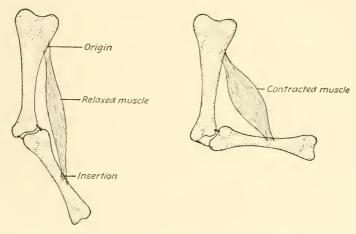
Fig. 22.7. Diagram illustrating the action of a flexor muscle. At the left the muscle is shown relaxed; at the right contracted. Note that the bone to which the muscle is inserted moves during contraction.

The muscle may be attached directly to the bone or, more commonly, by a connective tissue extension known as a **tendon**. When the muscle contracts, the bones at either end may move, but one end will probably move much more than the other. It is customary to call the point that moves the most the **insertion** and the point that moves the least the **origin** of the muscle. In the case of limb muscles, the origin is usually the end nearest the trunk; whereas the distal end of the muscle is the insertion.

For the muscle to be able to exert proper control over movements of the joints it must not only be able to initiate movements by shortening itself, but it must also be able to slow down movements by exerting a resisting force as the muscle is stretched by other forces as it attempts to contract. Without this property of muscle we would be unable to walk downhill and all our movements would be jerky, as muscles con-

tracted without any resistance from opposing muscles. This resisting force enables us to fix a joint in position as is done when we maintain a standing position.

To do all these things one would expect to find an extremely complicated mechanism. Actually, the arrangement is quite simple. Each muscle consists of a large number of muscle fibers; these are grouped together in **motor units.** The nerve which innervates the muscle is composed of many nerve fibers and one nerve fiber runs to each motor unit. When only one of these nerve fibers stimulates the muscle, only its particular group of muscle fibers is activated and only they contract. Thus, by stimulating varying numbers of nerve fibers the brain can regulate the number of motor units pulling at one time and consequently the force which the muscle as a whole exerts.

The way in which this system works may be illustrated by holding a book in your hand. If your brain stimulates enough motor units you will be able to exert enough of a pull to lift the book against gravity. With slightly fewer motor units in action, you will just balance the pull of the muscle against the force of gravity and will be able to hold the book in place. If still fewer motor units are stimulated gravity will pull the book down, but you will be able to lay it down gently on a table due to the resisting action of the muscle fibers that are being stretched while they are being stimulated to contract. Finally, if no motor units are being stimulated, your hand and the book will drop with a bang in the absence of any resisting force.

The movement of the body that results from such contraction is called the **action** of the muscle. Several muscle actions might be mentioned to illustrate this principle. Limb muscles which bend a part of the limb are **flexors.** Opposing muscles that straighten the limb out are **extensors.** Muscles which pull a limb away from the median body line are **abductors,** while those that pull it back toward the median line are **adductors.** Muscles that rotate a body part are called **rotators,** some of which move the structure clockwise and others move it counterclockwise.

There are always such opposing sets of muscles that do just the opposite things and purposeful movements of the body are only possible through muscle coordination, with just the proper degree of resistance and relaxation being exhibited by one set of muscles when its opposing set is contracting to move the body part.

If you have ever seen frog legs cooked, you were probably amazed at the activity of the legs when they were put in hot grease; they will almost jump out of the skillet. This is because the cells live for a long time after the frog is technically dead as an individual. Because of this characteristic, the muscles of frogs are ideal to demonstrate principles of
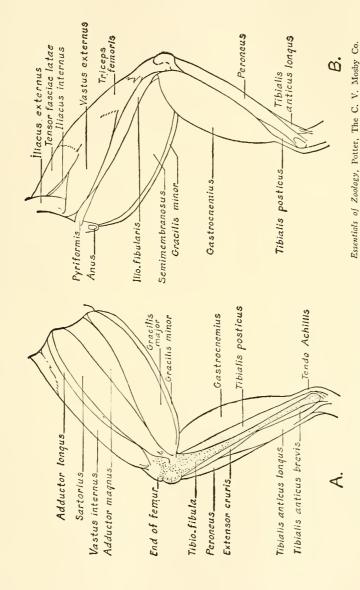
FIG. 22.8.   Diagram of the muscles of the hind leg of a bullfrog.   A. ventral view; B. dorsal view.

Essentials of Zoology, Potter, The C. V. Mosby Co.

muscle physiology. The calf muscle together with its connecting nerve may be dissected out to study the muscle nerve reaction. When the nerve is stimulated with a weak electric current the muscle will contract; as the strength of the current is increased the contraction becomes more vigorous due to the stimulation of greater numbers of the motor units. When all of them are being stimulated, however, the response cannot become greater even though the current is greatly increased. If the stimulation is repeated over and over the response will diminish and finally cease altogether. It might be assumed that this cessation is due to muscle fatigue, but if the wires are applied directly to the muscle, it will contract. We also know that a nerve fiber does not easily become fatigued. We may conclude, therefore, that it must be the connections between the end of the nerve and the muscle, the neuromuscular junc-
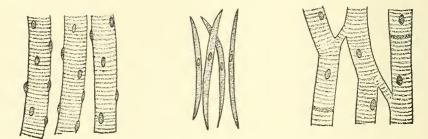
Fig. 22.9. Histological structure of muscle. At the left, striated muscle fibers from the skeletal muscle; in the center, smooth muscle cells from the visceral muscle; at the right, cardiac muscle fibers from the heart.

tion, which becomes fatigued first and the muscle fibers fail to receive the stimulus transmitted by the nerve. If the muscle fibers are stimulated directly with the electric current, the amount of their contractions will eventually become reduced due to the accumulation of waste products, chiefly lactic acid. When the concentration of lactic acid reaches 0.5 per cent, contractions cease entirely.

If a single muscle fiber is stimulated with a very weak current, it will not respond. When the current is increased until it is just strong enough to get a reaction, the muscle fiber will contract to its maximum capacity. A much stronger current will not increase the amount of contraction. This is known as the **all or none law.** The reaction is either all the way or none at all. It is a law which applies to many phases of physiology. It can be compared to the shooting of a rifle—if the trigger does not hit the cartridge hard enough it will not explode, but when sufficient force is applied to explode the cartridge it will throw the bullet just as far as if a hundred times as much force were applied in pulling

the trigger. As explained above, it is the number of motor units that contract that determines the strength of a muscle movement, rather than a variable amount of contraction of the individual fibers.

The second type of muscle in the frog's body is the **smooth** or **visceral muscle.** It is called smooth because, under the microscope, it appears as long slender cells, narrowing to a point at the end, with a single nucleus, and without striations. The name visceral is given because it is found primarily in the visceral organs. Smooth muscle is not as efficient as striated muscle; smooth muscle cells can shorten themselves to
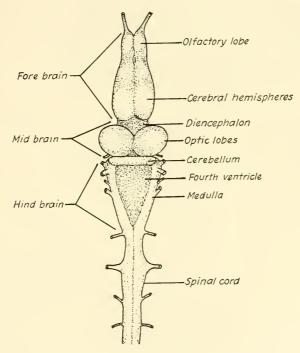
FIG. 22.10. Dorsal view of the brain of a frog.

one sixth of their original length when stimulated, while striated muscle cells can contract to one tenth of their normal length. The smooth muscles are mostly used to keep material moving through the alimentary tract, through peristaltic contractions as first described in Chapter 13. Their actions are controlled by branches of the autonomic nervous system.

The third type of muscle is **cardiac muscle.** This is found only in the heart. By microscopic examination we learn that the fibers are long and striated just as are those of skeletal muscles, but the fibers anasto-

mose freely; that is, they form a continuous network in which cross-connections join the fibers. The nuclei are in the center of the fibers rather than along the edges as in skeletal muscles. The contractions of the heart muscle are involuntary in nature as are those of smooth muscle, so cardiac muscle shows a combination of the characteristics of the other two. The heart muscle will continue to contract rhythmically even when
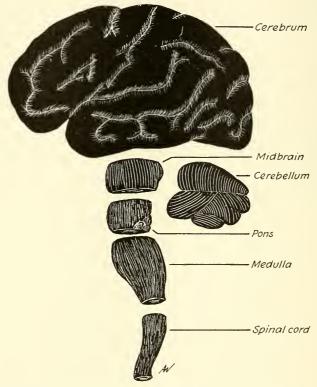
Fig. 22.11. Diagram of the parts of the brain of man. The parts have been separated somewhat for clarity.

its nerves are severed. When the heart of a frog is held in the hand, it will continue to pulsate for a considerable time. The ability to perform rhythmical activities is a fundamental property of protoplasm which, in cardiac muscle, has become greatly developed. The nerves that run to this organ serve to accelerate or to inhibit the rate of heart beat in accordance with the needs of the animal's body, but they do not initiate the beat.

The muscles of man show no distinctive differences from those of the frog, so there is no need for a separate discussion of them. Most of the

principles of muscle physiology that apply to all mammals have been worked out with frog muscles.

The Nervous System. This system has the general function of co-ordinating the various parts of the body with one another so that the body functions as a unit rather than as individual parts. For convenience of study it is divided into the **central nervous system,** consisting of the brain and spinal cord; the **peripheral nervous system,** consisting of cranial and spinal nerves; the **autonomic nervous system,** a set of nerve ganglia and nerves that control the involuntary body reactions; and the **sense organs.**

As in all vertebrates, the brain of the frog is divided into five regions, some of which are much more conspicuous than others. Part I consists
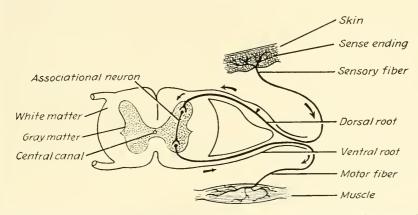
Fig. 22.12. Cross-section through the spinal cord showing how connections may be made in reflex action. The connections with nerve fibers going to and from the brain are not shown.

of two elongated **cerebral hemispheres** with a pair of olfactory lobes at their anterior ends—the **olfactory** nerves are attached to these. Part II is the inconspicuous **diencephalon,** to which is attached the pineal body dorsally and the pituitary gland ventrally. The **optic** nerves from the eyes enter the ventral side of the diencephalon. These two regions are often grouped together as the forebrain. Part III is the **midbrain,** which bears the conspicuous optic lobes on its dorsal surface. Two pairs of cranial nerves are attached to this region. (These are the **oculomotor** and **trochlear** nerves which run to the muscles which move the eyeballs.) Part IV is the **cerebellum** which is reduced to a thin band of nervous tissue just posterior to the optic lobes. Part V is the elongated **medulla** which is easily recognized by the large triangular opening on the dorsal side. Parts IV and V are often grouped together as the

hindbrain. Five pairs of cranial nerves are attached to this region. (These are: the **trigeminal,** which controls muscles of jaws, tongue, etc.; the **abducens,** which also connects with a muscle of the eye; the **facial,** which controls facial and ear movements and has to do with salivation
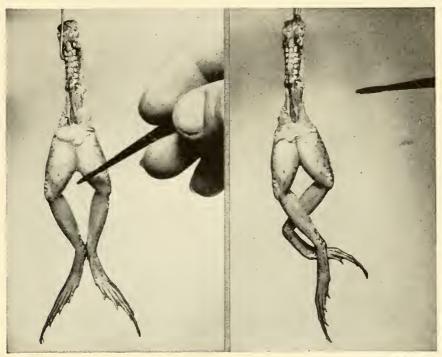
Photos by Winchester

FIG. 22.13. A complex reflex action in the frog. This frog has had the entire top of his head cut off, thus removing all of the brain except the medulla. However, it is still able to maintain a normal posture and, when stimulated with a needle, first raises itself and then gives a powerful leap. With the cerebrum missing from the body this frog could not have had any sensation of pain from the needle nor could the movement be considered voluntary. The reaction, therefore, is explained only on the basis of reflex action. These pictures were made with speed flash photography which gives an exposure of only one five-thousandth of a second and thus "freezes" the action.

and tasting; the **auditory,** which has to do with hearing and equilibrium; the **glossopharyngeal,** which is also concerned with salivation and tasting; and the **vagus,** which sends branches down to the heart, lungs, stomach, and intestine.)

When the brain is dissected, it is found to contain four cavities called ventricles which are connected to one another and with the canal

in the center of the spinal cord. These spaces are filled with the **cere-brospinal fluid** which is under pressure and helps hold the soft brain and spinal cord in shape. The fluid also fills the space between the brain and the skull. This helps protect the brain from injury due to blows on the head. It also is found between the spinal cord and the bony vertebral column.
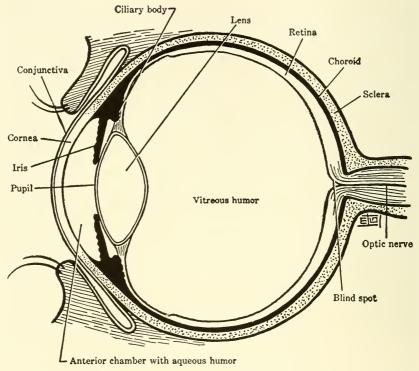
Photos by Winchester

FIG. 22.14.   The flexion reflex in the frog.   Even though the hind legs and a portion of the spinal column are the only parts remaining, this frog still has the power of reflex action.   When the leg is stimulated with dilute acid, it is drawn up vigorously in response.   The action was stopped by speed flash.

There are ten pairs of cranial nerves which are listed in our survey of the parts of the brain. All of these except the tenth run to parts of the head as we have seen. The spinal nerves come out of the spinal cord between the vertebrae. Nerves carry impulses only one way because these impulses can cross the nerve connections in only one direction. Hence, there must be some nerve fibers which bring impulses to the spinal cord or brain and others which carry them away. Those going to the spinal cord or brain are called sensory nerves, whereas

those going from the spinal cord or brain lead to muscles and are known as motor nerves.
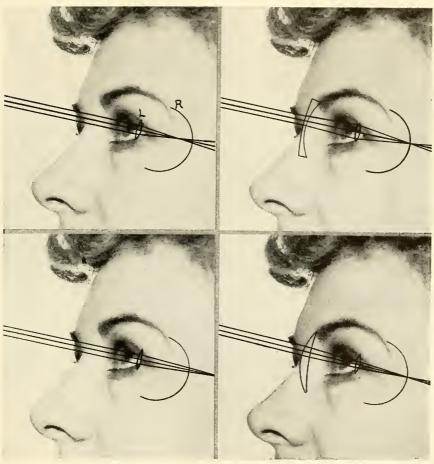
A simple nerve stimulation and motor reaction can be illustrated as follows. If one of the sense organs of touch on the foot were stimulated by pricking it gently with a pin, an impulse would be generated that would travel up the sensory nerve and enter the spinal cord. It

Elements of Biology, Strausbaugh and Weimer, John Wiley & Sons, Inc.

Fig. 22.15. Section through a human eye showing the parts found in a typical chordate eye.

would continue up one of its nerves within the spinal cord to the brain and the frog would know that it had been touched. Connections would be made and the impulse would travel back down one of the nerves within the spinal cord, out into a motor nerve, and arrive at one of the leg muscles, which would contract and move the foot from the pin. Such is the chain of events that regulates the thousands of adjustments that higher animals make to their surroundings. There is a slight delay in the stimulation and response, for it takes some time for the impulses to

make the proper connections through the brain, but when a stimulation is strong enough, the response will be more rapid due to the principle of **reflex action.** A person suddenly sitting on a pin does not take time to reason out what has happened before responding; the stimulation is so

Fig. 22.16. Diagram illustrating nearsighted and farsighted vision. The black lines represent rays of light originating from a distant point of light. The lens of the nearsighted person focuses these rays at a point in front of the retina and they spread out again to give a fuzzy image on the retina. However, when an artificial minus lens is placed in front of the eye the rays are spread slightly before reaching the lens of the eye and they come to a sharp focus on the retina. In the farsighted individual the rays reach the retina before they have come to a focus and, again, a fuzzy image results. In this case a plus lens may be put in front of the eye; this causes a slight convergence of the rays and a sharp focus on the retina.

strong that the proper connections are made in the spinal cord and the response comes quickly and vigorously.

The **autonomic nervous system** consists of two nerve trunks that run down the body on either side of the vertebral column with branches running out to those organs which are controlled automatically. They regulate the rate of heart beat, rate of respiration, secretion of digestive enzymes, movement of food through the intestine, the dilation and contraction of the pupils of the eyes, and the many other involuntary body reactions.
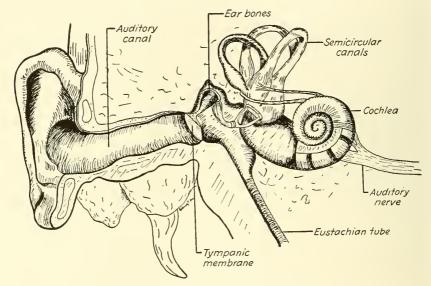
FIG. 22.17.   Diagram of the human ear.

The **sense organs** are also a part of the nervous system since they pick up stimulations and transmit impulses on the sensory nerves to the central nervous system. It is by means of these sense organs that a frog or a man keeps in contact with the outside world. We will describe these senses primarily from the human aspect and will point out any primary differences in the frog.

The sense of **sight** is localized in a pair of well-developed eyes. The vertebrate eye has a structure somewhat like a miniature camera with an iris diaphragm to regulate the amount of light which enters the eye, a lens which focuses the image, and a retina which receives the image in much the same manner as film is exposed.

The sense of **smell** is localized in the nasal cavity where there is a small patch of tissue containing olfactory sense organs. These marvel-

ous organs can detect the presence of extremely minute quantities of substances which we inhale along with the air we breathe. Some vertebrates, such as dogs, have a much larger patch of olfactory sense organs and, hence, have a much keener sense of smell than man or a frog.

The sense of **taste** is recorded by taste buds which are chiefly on the tongue. There are four main kinds of these which detect salt, sour, sweet, and bitter, respectively. Other properties which are associated with the flavor of foods are due to the odor, temperature, and texture of the foods as they are being eaten.
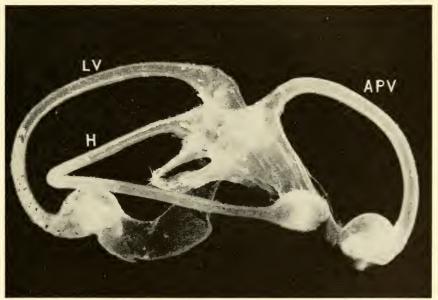
Photo by Winchester

FIG. 22.18. The semicircular canals from the internal ear of the dogfish shark. These are similar to the ones found in man, but are much easier to dissect out in the shark because they are embedded in cartilage rather than bone. The letters indicate the anterior-posterior vertical, the lateral vertical, and the horizontal semicircular canals.

The sense of **hearing** is localized in the ear. Sound vibrations are picked up by a tympanic membrane, transferred through the ear bones of the middle ear to the fluid found in the inner ear. Here are found the nerve endings which transmit the vibrations of different rates into impulses which go to the brain and give the impression of sounds of different tones. The tympanic membrane of the frog lies just back of the eye—in man it is at the bottom of an auditory canal which leads in from the outer portion of the ear.

Balance is a very important sense which depends primarily upon two different sets of sense organs. Within the inner ear there are three **semicircular canals** which are so placed that each is at right angles to the other two. The canals are filled with a fluid and within them there are delicate nerve endings which are sensitive to movement of the fluid. When the position of the head is altered or when there is a sudden acceleration or deceleration, the fluid will move most rapidly in the canals which lie in the same plane as the movement. This moving fluid stimulates the nerve endings and we are conscious of the movement even though our eyes may be closed. There is another method which enables us to determine the position of the head when it is not moving and there is no movement of the fluid in the semicircular canals. There are small stones of calcium carbonate, the **otoliths,** which are in a fluid-filled sac, the sacculus, of the inner ear. The sac is lined with nerve endings which are sensitive to contact with these bodies. The stones move by gravity so that they always stimulate the nerve endings which are down. This is similar to the action of the sand grains in the statocyst of the crayfish. Also, the sense of balance is aided by a system of sense organs, known as **proprioceptors,** which are located in the muscles and tendons. These help to bring about the complicated series of reactions which is necessary for the proper muscle coordination which we need to maintain our balance. In fact, all coordinated muscular response is in part dependent upon this set of sense organs.

There is a variety of sense organs of the skin and other epithelial tissues which may be grouped under the **tactile sense.** Some of these are sense organs of touch which are sensitive to contact. Extreme stimulation of some of these results in pain. Also, there are sense organs of pressure, heat, and cold. These sense organs are not evenly distributed on all areas of the body—some simple experiments will show that they are more numerous on the lips and finger tips than on areas such as the shoulder or thigh. The advantage of such distribution is easy to understand—we don't rub our shoulders against an object to learn what it feels like. In addition to these the frog has some sense organs in the skin which are sensitive to variations in the chemical environment—this enables him to recognize harmful chemical compounds which may contact the skin. Man's skin is so thick over most of the body that this sense is lacking, but it may be found on the mucous membranes which are found in the mouth and nasal cavities. You can test this by peeling an onion or by holding a bottle of ammonia near your nose.

REVIEW QUESTIONS

1. Why is it more difficult to pick a type animal for the chordates than for other phyla that we have studied?

2. What are the functions of the skeletal system?

3. Name the structures found at a movable joint and give the function of each.

4. What is a suture?

5. What structure in man is homologous to the urostyle of the frog?

6. What is the one specialized function of muscle cells?

7. Name the three kinds of muscles, tell where each kind is found, and give the histological features that distinguish each.

8. What is meant by the origin, insertion, and action of a muscle?

9. Explain how the brain regulates the degree of pull exerted by muscles so that a person can pick up a book, hold it for reading, and gently lay it down on a table.

10. How does heart muscle differ physiologically from the other types of muscles?

11. Distinguish between sensory and motor nerves.

12. What part of the nervous system regulates the involuntary body reactions?

13. List the sense organs of the frog and the human body and tell how each functions.

14. Compare the location of the common chemical sense in the frog and in man.

15. What parts of the human brain are proportionally larger than corresponding parts in the frog?

16. What are the four kinds of taste?

17. Name the five regions of the brain.

18. What parts of the brain are in the forebrain, midbrain, and hindbrain?

19. Explain how nerves control the rate of heart beat.

20. How can we prove that the neuromuscular junction becomes fatigued before the muscle becomes fatigued?

21. What is a motor unit?

22. Explain the all or none law.

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The Vertebrate Body (Cont.)

Nourishment, Respiration, and Distribution in the Frog and Man

The Digestive System. One of the primary concerns of the frog, as of all animals, is the obtaining of food. This is not too much of a problem in this instance, for the frog is very fond of insects, such as nice, fat, juicy flies, and there are certainly plenty of these available. The tongue forms an excellent fly trap; it is hinged onto the mouth at the front rather than at the back, as most tongues are, and it is covered with a sticky mucus. When a fly ventures too close the frog flicks its tongue out with amazing rapidity, the insect sticks to it, the tongue flicks back into the mouth, the frog swallows and calmly resumes his attitude of watchful waiting.

As the struggling fly reaches the throat the muscles carry it down to the **esophagus,** which carries it on to the **stomach** by means of **peristaltic** contractions. The stomach is lined with gastric glands that secrete hydrochloric acid and pepsin; the pepsin is an enzyme which begins the digestion of proteins, but it cannot function without the hydrochloric acid. The fly breaks up into smaller pieces due to the action of these secretions combined with the muscular action of the stomach walls which churn the food around vigorously. We are sometimes embarrassed by the gurgling sounds resulting from similar churning actions of our own stomachs when we are in polite company. When this phase of digestion has progressed sufficiently, the **pyloric sphincter,** which guards the exit from the stomach, opens and some of the food is squeezed into the upper end of the small intestine, the **duodenum.** Here the pancreatic juice from the **pancreas,** the bile from the **liver,** and the intestinal juices from the glands in the intestinal wall mix with the food. There are three enzymes in the pancreatic juice—a fat-splitting one, a starch-splitting one, and a protein-splitting one. The intestinal juices contain enzymes which split complex sugars into simple sugars. The bile is partly a waste product from the liver, but it also assists in digestion by breaking the fats into tiny droplets. It is an emulsifier.

Meanwhile the food has been churned up by segmentation movements of the intestine and has been gradually moved along by the peri-

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staltic waves until it passes into the **ileum** which makes up the remainder
of the intestine.

By this time the food moving through the intestine is chiefly in a
liquid state, for as food is digested it goes into solution.   The protein-
splitting enzymes have broken the proteins down into amino acids, the
fat-splitting enzymes have changed the fats into fatty acids and glycerol,
and the starch-splitting enzymes have reduced the starch to sugar.
There are numerous longitudinal folds on the inside of the small in-
testine which increase the area exposed to the digesting food.   These
folds are liberally supplied with capillaries.   The liquid materials in the
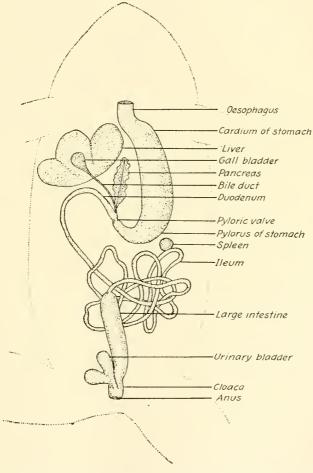
FIG. 23.1.   The digestive system of a frog.   The liver and pancreas have been folded
back from their normal position covering the duodenum and lower part of the stomach.

intestine come into close contact with these capillaries and the molecules
of digested food pass by diffusion through the walls of the folds and the
walls of the capillaries.

The liquefied foods are now in the blood and pass into the veins
where they are carried by the hepatic portal vein to the **liver.** We have
already mentioned bile secretion as one of the functions of the liver, but

Pharynx

Esophagus

Liver

Gall bladder

Bile duct

Duodenum

Pyloric sphincter

Pancreas

Jejunum

Ascending colon

Ileocecal
sphincter

Cecum

Appendix

Stomach

Transverse colon

Ileum

Descending colon

Sigmoid

Rectum

Anal sphincter
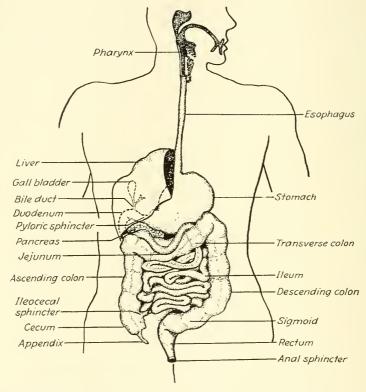
FIG. 23.2. The human digestive system. A part of the liver has been cut away to
show the part of the stomach lying beneath it.

it has several other important functions as well. It acts as a **storage
organ** for certain important products such as carbohydrates, fats, and
vitamins. As blood rich in these substances enters the liver and passes
into the capillary network which surrounds the cells, the liver will
absorb and store any excess. Sugar is stored in the form of glycogen
which is released gradually between meals and thus maintains the proper
balance of this sugar in the blood. The liver also **removes poisons** from
the blood—we would be more easily injured or even killed by small

doses of poisons, if the liver did not have this property. Mercury, for example, is stored in the liver and in the days when mercury compounds were used extensively in medicine, the liver was often badly damaged by the accumulation of excess mercury. After being filtered through the liver, the food is carried to the heart and then, after a quick trip to the lungs and back, it is carried by the arteries to all parts of the body. The tips of the smallest arteries again enter a capillary network where the food diffuses out through the capillary walls and into the body cells through the cell membranes.
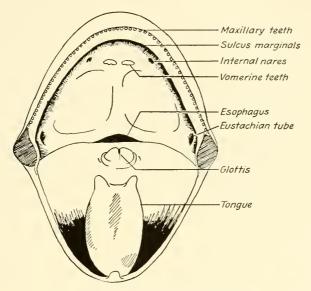
FIG. 23.3. The open mouth of the frog.

Back in the ileum, the indigestible part of the food passes on into the **large intestine,** which is greater in diameter than the small intestine. This material is still liquid, but the large intestine continues to absorb the water until the waste is in a semisolid condition. It is now referred to as **feces** and is ready to be egested. In the frog the feces are discharged through a cavity, the **cloaca,** to the outside. The cloaca also receives and discharges the products of the excretory and reproductive systems as well as the feces from the digestive system.

When this system is compared with that found in man we find that, although they are basically similar, there are some differences. Our method of ingestion is quite different. A man's tongue is fastened at the posterior end and has nothing to do with food getting. We have four kinds of teeth which are used for biting and chewing food. This

chewing performs several important functions besides making the food particles small enough to swallow. It mixes the food with the saliva, secreted by the salivary glands, which contains a starch-splitting enzyme, ptyalin. This makes a starchy food such as a cracker taste sweet if it is chewed long enough. The saliva also dissolves sugar and salt, a necessary preliminary to taste, since the taste buds on the tongue are stimulated only by substances in solution. The saliva also contains a sticky substance called mucin, which helps in swallowing by holding the particles of food together and by "greasing" them so that they will slide down the esophagus easily.

The human small intestine is not only much longer in proportion to body size than that of the frog, but it is also lined by millions of finger-like **villi,** each of which contains a double series of vessels, the lymph vessels or lacteals, which pick up and transport most of the digested fats, and the blood capillaries which do the same for the absorbed sugars and amino acids.

The human ileum enters the large intestine from the side leaving a blind sac, the **caecum,** extending beyond this connection. On the tip of the caecum there is a slender, worm-like process, the well-known vermiform **appendix,** a vestigial organ which frequently becomes inflamed and abscessed. There is no cloaca in man after birth—the digestive system has a posterior opening, the anus, which is separate from the openings of the other organs. There is a cloaca in the human embryo, however, but during embryonic development a partition separates the urogenital ducts from the termination of the large intestine and separate openings are formed before the infant is born.
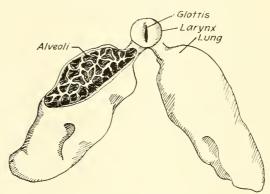
Fig. 23.4. The respiratory system of the frog.

The Respiratory System. The frogs are land animals so they have lung respiration, but it is not as efficient as that of more advanced animals

and is supplemented with oxygen absorption through the skin. However, oxygen cannot be absorbed from a dry surface and the frog will die if his skin dries out, for the lungs alone cannot supply sufficient oxygen for the body.

If you look at a frog from the side you can see the throat expanding and contracting at regular intervals. This is the respiratory movement of the frog; it is pumping air down into the lungs, by a method that is similar to swallowing water. First, the air is sucked into the **oral cavity** through the nostrils as the throat is expanded. Then the throat is contracted and valves close the nostrils so that the air is forced through the **glottis**, into the **larynx**, and to the lungs. The lungs are elastic and contract to force the air back out when the pressure is released. The larynx contains two narrow bands across it; these are the vocal cords and can
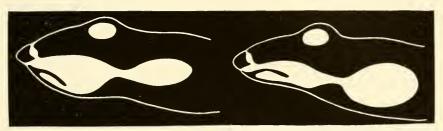
Fig. 23.5. Method of inhaling air in the frog. The floor of the mouth is lowered causing air to come in through the nostrils to fill the mouth cavity. Then, the nostrils are closed and the floor of the mouth is raised. This forces air into the lungs. The elasticity of the lungs then expels the air when the nostrils are opened.

be stretched so as to vibrate as air passes over them to make sound. They can produce various sounds with a definite meaning. Frogs have a cry of alarm, a cry of pain, and a sex call, in addition to the croaking that seems to have no particular meaning. The bullfrog has very heavy vocal cords, which produce deep booming sounds that echo through the surrounding countryside with a force all out of proportion to the size of the frog.

The **lungs** are two small sacs which are divided internally into many smaller sacs, the **alveoli**. This greatly increases the absorptive surface. These alveoli are lined with a network of fine capillaries so that the air comes in close contact with the blood. The oxygen, being more abundant in the air than in the blood, diffuses through the thin membranes between and is absorbed by the hemoglobin in the red blood corpuscles. On the other hand, there is more carbon dioxide in the blood than in the air, so it diffuses in the opposite direction and is expelled when the air is exhaled. The same principle applies to the absorption of oxygen and the release of carbon dioxide from the skin.

The human respiratory system shows several important differences when compared with that of the frog. Because our skin is so thick and dry, we cannot absorb oxygen through our skin. However, the human body has a much higher rate of metabolism and in consequence needs a much larger supply of oxygen. This extra oxygen is supplied by a more highly developed system of alveoli within the lungs which gives a much greater surface exposed to the air in proportion to size than the less complex lungs of the frog.
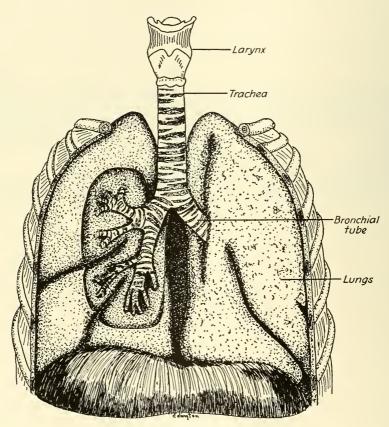
FIG. 23.6.   Diagram of the lower respiratory tract of man.

Within our larynx, as in the frog, there are vocal cords. We have a trachea, or windpipe, leading from the larynx. The frog has no trachea. Our trachea is supported by C-shaped cartilage rings which prevent it from collapsing when we inhale. At the posterior end the trachea branches into a pair of bronchi which extend out to the lungs

on either side of the chest. The bronchi branch and rebranch within each lobe of the lungs and finally end in a cluster of alveoli.

Our method of getting air into our lungs is quite different from that of the frog. By raising the ribs and lowering the diaphragm we are able to increase the size of the chest cavity. When this is done the lungs expand and the pressure of the outside atmosphere forces air through the nose or mouth to fill the extra space in the lungs which has been
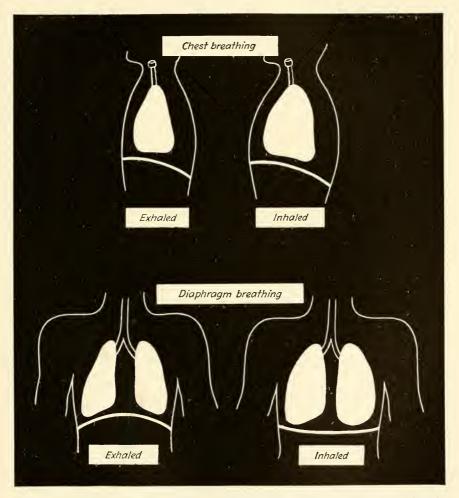
FIG. 23.7. Diagram to illustrate the method of respiration in man. When the chest is expanded the chest cavity becomes larger and the lungs expand to fill it; this draws the air in through the nostrils. When the diaphragm is lowered the chest cavity also becomes larger with a corresponding expansion of the lungs. Most persons use a combination of the two methods in normal respiration.

created by this expansion. This is known as inhalation or inspiration. Exhalation, or expiration, occurs when the ribs are lowered and the diaphragm is raised—these actions decrease the size of the chest cavity and force air back out through the nose or mouth. This method functions only so long as the chest cavity is intact—should it be punctured, outside air could enter between the lungs and the chest wall and there would be no lung expansion accompanying chest expansion. Strange to say, the chest cavity is sometimes punctured purposely as a means of treatment for tuberculosis. A needle is used to puncture the chest wall and air is injected in between the chest wall and the lung. This causes a collapse of the lung which gives it a maximum opportunity to heal when it is thus freed of its duties in respiration. The chest cavity is in two separate sections and the lung on the opposite side can go ahead and function normally.

The Circulatory System. Circulation is one of the most vital and interesting of the life processes. It may seem dull if studied as an inanimate group of vessels, but if we could visualize the activities of this system by first-hand observation the wonders of the world would seem dull in comparison. Suppose we make a tour of the circulatory system of the frog as we would tour Carlsbad Caverns or some other great scenic wonder. Of course, we are much too large, with our gross macroscopic eyes, to begin to see the details of this system, so we must make ourselves smaller, say about the size of a medium-sized bacterium, or one five-thousandth of an inch in height.

We start our journey on the foot of a frog which seems to stretch out for miles on either side of us. We find an abrasion in the skin where blood is oozing out, so we enter one of the capillaries through this opening. We cling to the side of the capillary to get our bearings before starting our journey. The capillary seems as wide as a river and the blood is rushing past rapidly. We have read a guide book and are able to identify the parts of the stream flowing past. The liquid part is a clear, straw-colored fluid, which is the **plasma.** In it are floating huge bodies of different sizes and shapes. Most of these are large, elliptical, flattened bodies, which seem to be about twenty by thirty feet, and bear an elliptical nucleus in their center. We notice that they are different colors, some are bright red and others are a dull dark red. We see one of the bright ones approaching us and we duck into a small cavity to keep from being crushed. It bumps against the capillary wall and adheres to it for a few moments. There, before our very eyes, we see the bright red color fade into the dull red hue. As it pulls away, we remem-

ber that this is an **erythrocyte,** or red blood cell, and we have just witnessed the diffusion of oxygen from this cell into the oxygen-hungry surrounding tissues.

We also see irregular-shaped bodies that sometimes contain lobed nuclei. These are rapidly accumulating around the break in the capil-
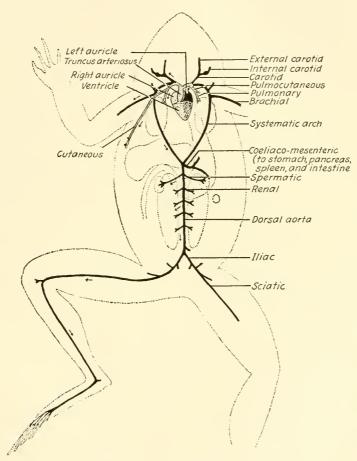
FIG. 23.8. The heart and principal arteries of the frog.

lary through which we entered. We noticed several objects have entered this abrasion along with us that appear as bunches of huge grapes. There is one of these clusters floating just in front of us, but one of the multi-nucleated bodies approaches and throws broad pseudopodia out around it like the tentacles of an octopus. These tentacles close in and snap together and we now see the foreign cluster inside the huge cell.

We hope that we are not discovered to meet a similar fate. We realize that these are the **leucocytes,** white blood cells, which are the watch dogs of the blood, and the object that they engulfed was a group of staphylococcus bacteria, which are responsible for many infections.

Finally, there are spindle-shaped cells, the **thrombocytes,** floating past in the plasma. We watch some of these as they flow through the break in the capillary and see a remarkable thing. When they touch the outer skin they burst like a balloon liberating a fluid that was contained within them. This fluid, upon mixing with the plasma, forms a tough, fibrous clot which is rapidly sealing the break and the flow of blood through it is soon stopped. We realize that these cells are responsible for the important process of blood clotting.

We decide to explore this marvelous system further, so we hop on an erythrocyte as it floats past and go swirling along in the stream of plasma. We notice that the size of the vessel in which we flow becomes larger as it is joined by many other small vessels and we are soon floating slowly in a huge vessel that appears miles across. All of the erythrocytes are now a deep dark red in color and we realize that we have passed into a vein which our guide book tells us is the **femoral vein.** We pass by the large opening of the pelvic vein and are in the **renal portal vein.** As we approach the kidney, the vessel gives off many branches which become smaller as they rebranch and we soon find ourselves again in a capillary. Here the pressure is very great and almost crushes us, for the vessels bringing the blood in are larger than those carrying it away. Under this great pressure we can see some of the plasma with its dissolved minerals being squeezed through the capillary walls into the tubules of the kidney. A little later the tremendous pressure is diminished and much of the water and useful minerals are reabsorbed into the blood. We next flow into the large **postcaval vein** and on into a huge cavity, the **sinus venosus.** Beneath us we can feel the mighty pulsations of the heart, which cause this entire region of the body to heave in an alarming manner. Suddenly, directly beneath us, valves open up and we are engulfed in a huge whirlpool that sucks us through an opening into the **right auricle.** We have hardly had time to regain our composure when the walls of the auricle come crushing in on us and we are forced through another valve into the **ventricle.** We know what is to follow so we cling to our raft as the ventricle closes in with a mighty force and are thrown out through another valve into the **conus arteriosus.** This soon branches into three parts, but most of the first blood to leave the ventricle goes into the first branch, which is the **pulmocutaneous artery.** As it forks again, we take the **pulmonary artery** to the lungs.

We soon reach small capillaries that encircle an alveolus. We can
see the sac swell like a huge balloon as the air is inhaled and then par-
tially collapse as the air is exhaled. Our erythrocyte contacts the capil-
lary wall and, as the oxygen particles enter, it assumes a brilliant scarlet
hue.
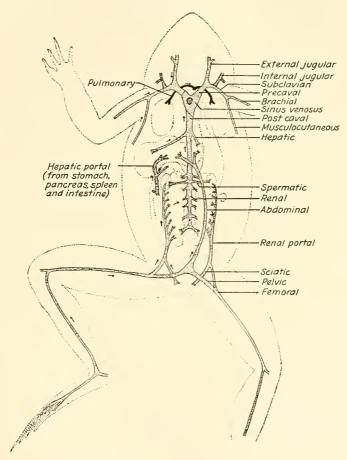
FIG. 23.9. The principal veins of the frog.

We go back to the heart by way of the **pulmonary vein,** but this time
enter the **left auricle.** The frog has only one ventricle, so we next enter
the ventricle for a second time. This time we are on the opposite side
however; we are on the left side of the ventricle and the corpuscles on
the right side are all a dull red color, for they have come from the right
auricle, while those surrounding us are bright red. The opening to the

conus arteriosus is nearer the right side, so when the ventricle contracts the blood with the dull-colored corpuscles goes out first, then we follow. We pass the pulmocutaneous branch, but it is filled with the unoxygenated blood so we continue into the second branch, the **systemic arch** which carries us around to join the **dorsal aorta** running down the back. We pass numerous branches leading off to the stomach, intestines, and other internal organs, then enter one of the **iliac arteries,** leading to a leg.
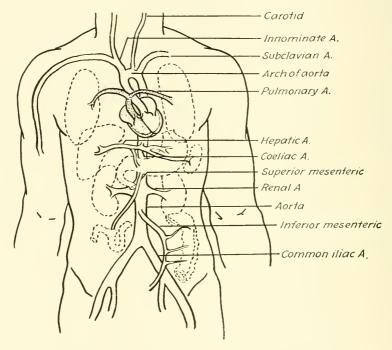
FIG. 23.10.   The larger arteries of the human body.

This continues down the leg as the **sciatic artery,** and we soon find ourselves back in our original capillary.   We manage to slip through a tiny hole in the blood clot and again expand ourselves to our normal size.

Never again can we look at a frog and think of it as a dull, uninteresting creature when we recall the marvels that we have just witnessed. Yet, as we look at our road maps (diagrams of the circulatory system, Fig. 23.8 and Fig. 23.9), we notice that there are many other routes which we could have taken that would have been just as interesting; through the spleen, where we could have seen worn-out red corpuscles removed for destruction; through the intestines, to see food absorption;

through the liver, where poisons and foreign bodies are removed; and so on.

A trip through the circulatory system of man would be somewhat similar. We would notice that the erythrocytes are considerably smaller, they are disc-shaped rather than elliptical, and they do not have a nucleus as the frog red blood cells have. The thrombocytes are disc-shaped rather than spindle-shaped. We would not have passed through the

Internal jugular
External jugular
Subclavian V.
Innominate V.
Superior vena cava
Pulmonary V.
Heart
Inferior vena cava
Hepatic portal
Renal V.
Common ilia V.
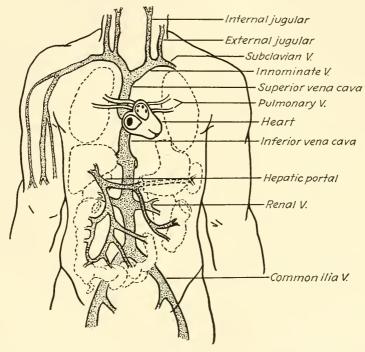
FIG. 23.11. The larger veins of the human body. All of the veins carry unoxygenated blood except the pulmonary veins which bring the freshly oxygenated blood from the lungs to the heart.

kidney on our way to the heart, for only arteries take blood to the kidneys in man. Neither would we have gone through a sinus venosus, for this structure is not present in the higher vertebrates. Also, man has four chambers rather than three in his heart, so we would not have entered the same ventricle twice. Because of this extra ventricle there is no chance for the oxygenated and unoxygenated blood to mix, for there is a separate auricle and ventricle for each type of blood.

We should not close our discussion of the circulatory system without mentioning **lymph,** since this substance is such an important aid in the

absorption and distribution of products in the body. Lymph consists of the liquid part of the blood which filters out of the small capillaries to bathe the tissues of the body directly. In the intestine there are small lymphatic vessels called lacteals that aid in the absorption of food. There are other special lymphatic vessels in the body that collect the lymph after it has been in contact with various body tissues to give up its food and to absorb excretory wastes. Eventually, the lymph finds its way back into the blood through veins in the neck region and again becomes a part of the blood.

The lymph will contain leucocytes, but no erythrocytes or thrombocytes. This is possible because the amoeboid nature of the leucocytes enables them to squeeze through the tiny openings of the capillaries along with the liquid part of the blood. Since these are the corpuscles that fight germs of infection they are valuable additions to the lymph, for germs entering through the skin could spread over the body through the lymph before they reached the blood if there were no leucocytes in the lymph to combat them.

In the frog there are two pairs of lymph hearts, an anterior pair and a posterior pair, that pump the lymph back into the veins. These are not present in man, however, and we are dependent on muscular contractions to keep this important fluid moving until it is forced back into the large veins in the neck region. Numerous valves in the lymph vessels allow the fluid to move only in the right direction. As the body muscles contract, the lymph is squeezed along. This is another reason why physical exercise is necessary for a healthy human body. In man lymph vessels enter masses of cells called lymph nodes and the lymph is thoroughly filtered as it winds around through tiny spaces in the node. This is very important because bacteria are often picked up by lymph vessels, and these bacteria are soon destroyed in the lymph nodes. When we have an infection in a finger and bacteria are very numerous, the nodes on the inner surface of the upper part of the arm may enlarge and produce a tender spot in this region. The tonsils are lymph nodes that project into the pharynx and help guard us from infections. As most of us know only too well, these tonsils may become so badly damaged in their battle with disease that we must regretfully part with them.

The Human Blood Types

We should not leave a discussion of the circulatory system of man without mentioning the blood types. These are of great significance in blood transfusions, settling cases of disputed parentage, and identification in criminal investigation. There are four major blood types which

are designated as **O, A, B,** and **AB.** There is no demonstrable differ-
ence in the quality of blood of the four types—we cannot say that any
one is more efficient than another. The different types of blood differ
in the presence or absence of certain substances known as antigens in
the red blood cells, and by corresponding antibodies in the blood plasma.
Fig. 23.12 shows the composition of the different types of blood accord-
ing to antigens and antibodies. If blood with the A antigen in the red
cells is mixed with blood that contains the A antibody, there will be a
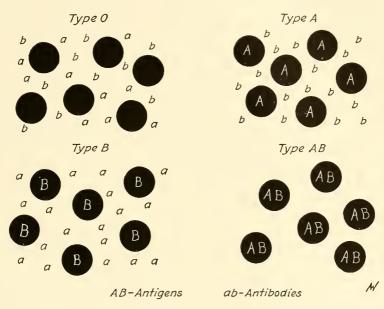
Fig. 23.12. Diagram to illustrate the antigen-antibody constituents of the red cells and
the plasma of the blood. Capital letters represent antigens; these are within the cells.
Small letters represent antibodies; these are in the plasma. Whenever antigens and
antibodies of the same letter come together, there is agglutination of the red cells
involved.

clumping of the red cells containing the A antigen. If this clumping
occurs in the blood vessels to any great extent during a transfusion,
death is very likely to result. Hence, blood is carefully typed before
transfusion to avoid such clumping in the veins of the recipient. The
method of determining a person's blood type is shown in Fig. 23.13.

 There have been cases where transfusions of the proper type of
blood have been given and still there was a severe reaction and clump-
ing of the blood cells being given. Such cases can result from the
presence of another antigen which is known as the **Rh factor.** It is
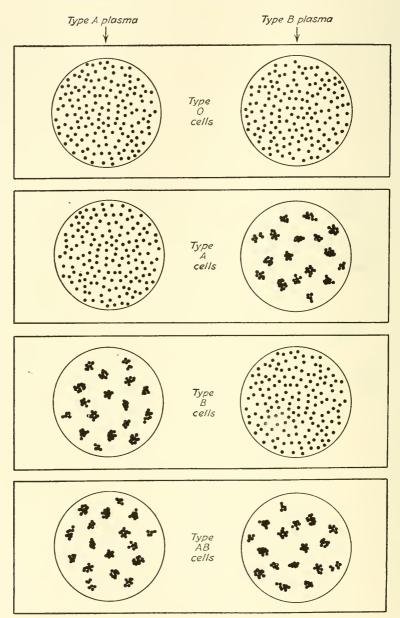
Fig. 23.13.   Method of blood typing.   A person's blood type may be determined by mixing a drop of his blood with plasma from type A blood and with plasma from type B blood.   If the blood being tested is type O the cells will be evenly distributed in both cases when examined under the microscope.   If the blood is type A the cells will be evenly distributed in the A plasma, but will be clumped together in the B plasma. Type B blood will show just the reverse reaction.   Type AB blood will clump in both types of plasma.

named from the Rhesus monkey in whose blood it was first demonstrated. All Rhesus monkeys and about 85 per cent of the Caucasian race in the United States carry this antigen. We say that these are Rh positive. The 15 per cent who do not carry the antigen are Rh negative. Normally, the blood plasma of an Rh negative person will

Negative mother
Negative child
Baby normal

Same mother
Positive child
Baby normal
Mother sensitized

Same mother
Second positive child
Baby born with
erythroblastosis
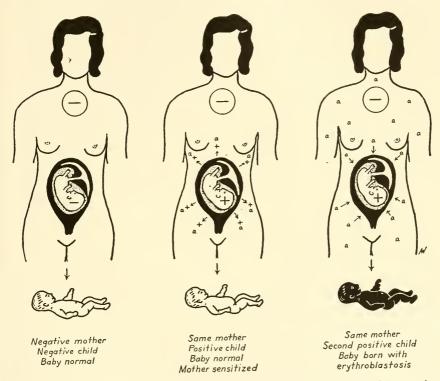
FIG. 23.14. How the Rh factor may cause erythroblastosis. When an Rh negative woman bears a negative child there is no trouble. Neither is there any trouble with her first positive child, but the Rh factor from this child may cause her to become sensitized and her body then contains Rh antibodies. Future positive babies will develop erythroblastosis due to the reaction of these antibodies with the Rh factor in the embryos.

not carry any antibodies for the Rh antigen, but such antibodies may be developed if a person contacts the antigen. This is somewhat like the development of antibodies against the antigens which are present in disease germs after the body is invaded with these germs. Such antibodies help us fight these germs in future contacts with them. When a negative person receives a transfusion from a positive person, there will be no reaction if this is the first such transfusion and the

bloods are properly matched for type. This contact with the Rh factor, however, may cause the production of antibodies against it and a second transfusion from the same person could prove fatal.

Also, the Rh factor has significance in childbirth in some instances. When a negative woman marries a positive man, she may bear a positive child. Her first positive child will be born normally, but she may develop some Rh antibodies as a result of this contact with the Rh factor within her body. If sufficient antibodies are formed, her second positive child may be born with a serious blood defect known as erythroblastosis, which is frequently fatal to the child unless vigorous steps are taken to save it. This condition in the child is brought about by the reaction of the antibodies of the mother's plasma with the Rh antigen in the blood of the child. Such a condition can arise only in marriages between negative women and positive men. Couples with such a combination should realize the possible danger and receive sound medical advice as their children are born.

REVIEW QUESTIONS

1. Trace food through the alimentary tract of the frog.
2. Give three important functions of the liver.
3. Tell how the frog gets air into its lungs. Compare this method with that found in man.
4. Why will a frog die if its skin dries out?
5. Tell how sound is produced in the larynx.
6. Name the types of blood corpuscles and give the function of each.
7. Why is the three-chambered heart of the frog less efficient than the four-chambered heart of man?
8. How do the erythrocytes of man differ from those of the frog?
9. What is lymph and what is its function?
10. What is the importance of physical exercise in relation to lymph?
11. Why do we call the vermiform appendix a vestigial organ?
12. What type of food is digested in the intestine and by what enzyme?
13. What enzymes are secreted by the pancreas?
14. What vessels pick up the digested fats, the sugars, the amino acids?
15. What systems open into the cloaca in the frog?
16. How does puncturing the chest wall help treat tuberculosis?
17. What is the function of the cartilage rings of the trachea?
18. How is lymph returned to the blood vessels in the frog and in man?
19. How do the lymph nodes purify the lymph?
20. Why is it important that blood be typed before transfusions are given?
21. If some blood from a person with type AB blood is mixed with some plasma from type O blood, what would happen and why?
22. Explain how the Rh factor may cause erythroblastosis in a child.
23. List all of the Rh combinations of couples who would never need to worry about possible Rh induced erythroblastosis in their children.

The Vertebrate Body (Cont.)

Excretion, Reproduction, and Regulation in the Frog and Man

The Excretory System. When we first studied the life processes in amoeba we found that the elimination of the waste products formed in the process of oxidation of food within the cell was a necessary reaction in the life of that animal. However, there were no special structures required, for diffusion of the wastes through the cell membrane into the surrounding water was simple. Excretion is just as important in the chordates, but because of their larger and more complicated bodies it must be done by special organs designed for this purpose. These organs are the **kidneys** which, in the frog, are two flattened, elongated, reddish brown bodies attached to the dorsal wall of the body cavity.

The excretory waste is generated in the cells as a part of their metabolic activities and diffuses out through the cell membrane into the surrounding blood and lymph. It reaches the kidneys through two entirely different blood vessels: the **renal arteries,** that branch from the dorsal aorta; and the **renal portal vein,** that carries venous blood picked up from the posterior region of the body. It is taken away from the kidneys by the **renal veins.** Within the kidney there are many small capsules containing **glomeruli.** A glomerulus is a network of capillaries. The blood vessel entering each glomerulus is larger than the vessel leaving it. This creates a pressure within the capillaries and some of the water and minerals of the blood are squeezed out into the surrounding capsule. This liquid then flows down little tubules where part of the water and the minerals needed by the body are reabsorbed by the blood. That which is not absorbed continues down the tubules and eventually empties into two ducts on the lateral surface of the kidneys as **urine.** These ducts are commonly called **ureters,** since this word is used to refer to the tubes that carry urine from the kidneys in the highest vertebrates, but in the male frog these ducts also carry sperms. Because of this it is somewhat more accurate to refer to these as **urogenital,** or **Wolffian,** ducts in the male frog. The urine flows down these ducts and empties into the cloaca. There is a bilobed **urinary bladder** hanging from the

ventral side of the cloaca into which the urine may back up until ready
to be eliminated.

In human excretion all the blood which reaches the kidney is carried
by the renal artery and returned to the venous system by the renal vein
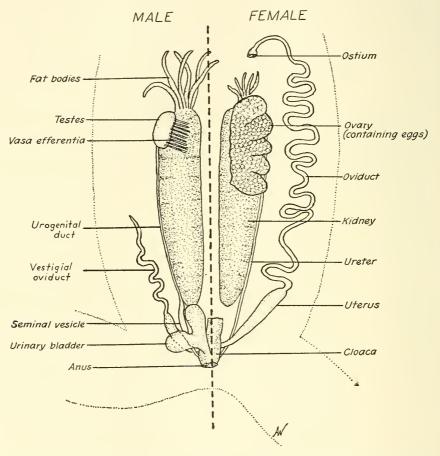
FIG. 24.1. Urogenital systems of the frog. The organs of the male are shown on the
left and those of the female on the right. The urinary bladder is present in both sexes
although it is tilted over on the male side in this diagram.

—there is no renal portal vein in man. The human kidney is more com-
pact than that of the frog. It consists of an outer **cortex,** an inner
medulla, and a cavity which is known as the **pelvis.** The kidney tubules
are arranged in groups called pyramids and each pyramid has a projec-
tion, the papilla, extending into the pelvis. The indented side of the
kidney, the hilum, is the region where the blood vessels enter as well as

the duct which in the human body is a true ureter in both sexes. The
kidneys lie behind the body cavity; that is, they are between the peri-
toneum and the muscle wall of the back. This makes it possible to
operate on the kidney to remove stones from the pelvis by going through
the back without actually entering the body cavity. This keeps air out

Dorsal aorta

Vena cava

Renal artery

Renal vein

Kidney

Ureter

Urinary bladder

Urethra
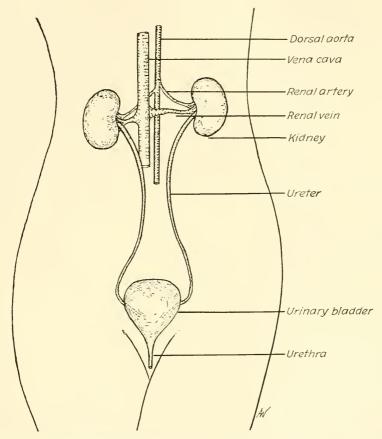
FIG. 24.2. Diagram showing the position of the excretory organs in the human body.

of the cavity and greatly reduces the danger of peritonitis, an infection
of the membranes covering the organs.

The ureters empty directly into the urinary bladder which is capable
of great distention. The bladder in the female empties directly to the
outside by means of an elongated neck, the **urethra**. In a man the ex-
cretory system gets mixed up with the reproductive system again, but
not as intimately as in the frog. The sperm ducts join the urethra just

below the bladder, and the urethra, therefore, carries both urine and the semen containing the sperms.

Physicians often analyze the chemical nature of urine as a means of diagnosis of disease. This gives valuable data about the function of other organs as well as the kidneys. For example, sugar in the urine is frequently a sign of disease of the pancreas called diabetes. In addition to the urea and uric acid present in normal urine, the excess salts in the diet are discharged by way of the kidneys. These include salts

Cortex

Medulla

Renal papilla

Renal sinus

Ureter
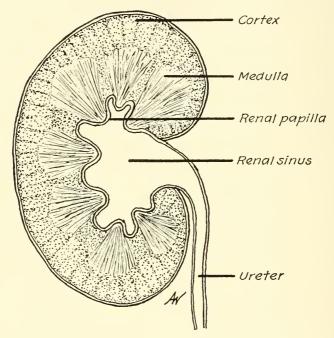
Fig. 24.3 Diagram of a section through a kidney and its connecting ureter.

of sodium, potassium, calcium, and magnesium; all of which are present in greater quantities in the urine than in the blood.

The Reproductive System. The frogs are the first of the chordates to adapt themselves to life out of the water. They have been fairly successful in every system except reproduction, for in this system they are like the water animals. Water is required to transfer the sperm to the eggs and since the eggs cannot hatch on the land, they must be laid in the water.

Frogs are ordinarily individualists and pay little attention to other members of their race, except perhaps to eat them if one small enough to swallow is found. However, during the spring they become gregarious

and gather in large groups. The females are usually distinctly larger and their bodies are distended with eggs at this season. The smaller males have an enlargement on the inner digit of the front legs which distinguishes them from the females. The males develop the clasping instinct at this time and climb on the backs of females and clasp them around the body with their front legs. This instinct is so strong that the body of the male can be cut in two and he will still retain his grip. He will retain his hold until the female lays her eggs which may be several days later. When she feels the urge she dives in the water and, probably
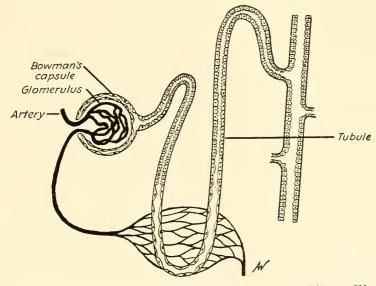
Fig. 24.4. Diagram of a renal collecting unit in the cortex of the kidney. Water and dissolved minerals are squeezed out of the capillaries in the Bowman's capsule. Some of the water and minerals needed by the body are then reabsorbed by the capillary bed at the loop of the tubule.

aided by squeezing from the male, lays her eggs. As the eggs are laid the male is stimulated to release his sperms which settle down and fertilize the eggs. The male has no copulatory organ, so there can be no internal fertilization and water is necessary for the sperms to swim to the eggs. The further development of the eggs is discussed in Chapter 33. After releasing the sperms, the male loses his clasping instinct, in fact loses his interest in the female altogether, and releases his grip and goes his separate way until he feels the biological urge again the following spring.

Internally we find the reproductive systems given over to the production of gametes and the release of them from the body. In the male

there are two small white **testes,** near the anterior end of the kidneys, that produce sperms. These travel through delicate little tubules, the **vasa efferentia,** into and through the kidneys and to the urogenital duct which lies along the lateral side of the kidneys. Thus this duct serves as both a ureter and a sperm duct. In some frogs this duct enlarges and forms **seminal vesicles** just before it enters the cloaca. The sperms are stored in these seminal vesicles before ejaculation.

In the female the **ovaries** are found at about the same location as are the testes in the male. They may be greatly enlarged so that they almost

Seminal vesicles
Vas deferens
Urinary bladder
Ejaculatory ducts
Prostate gland
Urethra
Corpora cavernosa
Cowper's gland
Penis
Epididymis
Prepuce
Glans
Testis
Scrotum
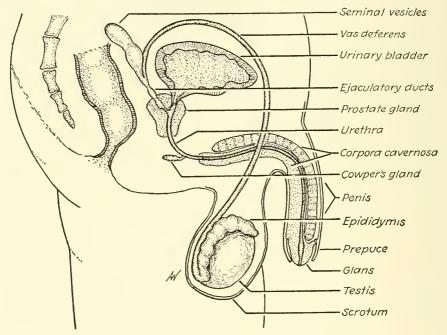
FIG. 24.5. The male reproductive system.

fill the entire coelom just prior to the sexual season. At other times they will not be as large as the kidney. As the sexual season approaches, the eggs mature and break out of the ovary into the coelom. At the anterior end of this cavity is the opening to the **oviduct,** the **ostium.** The ostium is funnel-shaped and, by some means, the eggs are attracted to this opening, enter in and pass down the long coiled oviduct to a posterior enlargement, the **uterus,** where they are stored. During the breeding season the uteri and the oviducts will be greatly distended with eggs. These are shed and fertilized as previously described.

When we come to compare these systems with those found in human

beings we find quite a number of differences.   Since the frog depends on
water for transference of the sperms to the eggs there is no male copula-
tory organ.   In man, however, the eggs are fertilized internally and the
male has a copulatory organ, the **penis,** which is used for this purpose.
The testes are in a different position in man; they are suspended outside
the body in a **scrotum,** for it seems that human sperms cannot develop in
the high temperature found inside the body cavity.   Occasionally the
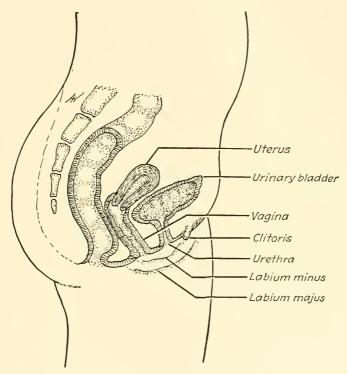
Fig. 24.6.   The female reproductive system.

testes remain in the body cavity in man.   An individual with this con-
dition is almost always sterile, but may become fertile if the testes are
brought down through the inguinal canal into the scrotum by a surgeon.
The vasa efferentia pass into a structure that partially envelops one side
of the testis; this structure is known as the **epididymis.**   From this the
sperms pass into the **vas deferens** (pl. vasa deferentia) which runs back
into the body cavity where it joins the urethra.   The **seminal vesicles**
are glandular attachments on the sides of the vasa deferentia which
secrete a fluid that is necessary to stimulate the sperms to active move-

ments at the time of copulation. The persistence of a large inguinal canal in the body wall of a man often results in inguinal hernia when a fold of the intestine is pushed down through this canal.

In a woman the ostium of the oviduct is closely connected to the ovary, so that the eggs which break out of the ovary usually drop right into it rather than going first into the body cavity and then finding their way to the ostium. Sometimes they do fall free in the body cavity and in certain rare cases have even been fertilized there and started embryonic development. The uterus of a woman is the place where the embryo develops rather than just a temporary storage place for eggs as in the frog. The human embryo derives nourishment from the uterus of its mother through its placenta and, therefore, it is not necessary for the human egg to store a large amount of food in the form of yolk as is the case in the frog egg. In a woman the single uterus opens to the **vagina,** which leads to the outside, while in the frog the two uteri open into the cloaca.

There is no seasonal cycle of reproduction in human beings as there is in frogs, but the activity of this system is somewhat stimulated in the spring of the year so the well-known quotation, "In spring, a young man's fancy . . . ," has some biological basis. There is a monthly cycle of ovulation in a woman that somewhat corresponds to the yearly cycle of ovulation in the frog, but a woman normally releases only one egg from her ovaries during ovulation while the frog may release hundreds.

The Endocrine System. There is a series of secretory glands located in various regions of the chordate body that have no ducts to carry their products. For this reason they are sometimes called ductless or endocrine glands. These glands secrete vital substances called **hormones** that are absorbed by the blood and lymph flowing through the glands and carried to cells all over the body. The hormones are regulators that govern many of the vital body reactions. The frog possesses endocrine glands and hormones which are similar to those found in man. However, most of the research on this body system has been done on the higher vertebrates including man. Therefore, it will be best for us to make our study of this system on the glands and hormones as they are found in the human body.

The **thyroid glands** are endocrines located in the neck on either side of the trachea connected across the front by a narrow isthmus of thyroid tissue. They secrete a hormone, **thyroxin,** that regulates the rate of metabolism in the cells of the body. A person with an excessive secretion of this hormone, **hyperthyroidism,** will have a high rate of metabolism. This results in a number of symptoms characteristic of this condition. With a high rate of metabolism there is a high rate of heat pro-

duction, so the person usually has no trouble keeping warm. People with this condition may be perspiring in a room that is chilly to others. They burn more food than the average person so they usually have a
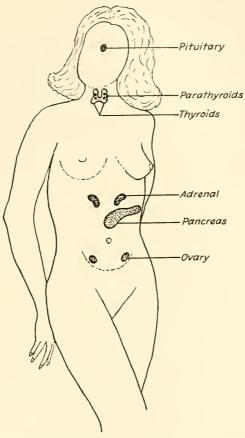
FIG. 24.7. Diagram showing the location of the endocrine glands in the body of a woman. They are the same in a man except the testes are found instead of the ovaries and they are suspended in the scrotum outside the body cavity.

ravenous appetite, yet this extra food is burned, not stored, and they do not gain weight readily and often are underweight. Because of the high rate of metabolism the nerve cells are highly sensitive and such people may be nervous and excitable with an accelerated heart beat. Persons with hyperthyroidism may be relieved of these symptoms by the surgical removal of a part of the overactive thyroid gland, or by destruction of part of its cells through the use of X-rays.
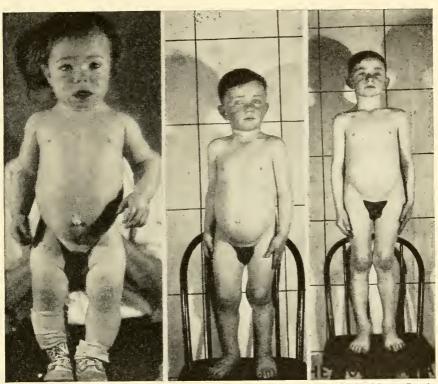
When there is a deficient secretion of thyroxin, **hypothyroidism,** there will be a correspondingly low rate of metabolism. This causes a series of symptoms that are about the reverse of those described for persons with an overactive gland. There will be low heat production and the person may feel chilly while those around him are comfortable or even warm. Such persons may not have much of an appetite, yet, in some cases, they may be overweight because much of the food that they eat is not burned, but stored in the form of fat. They may exhibit a mental sluggishness, lowered heart beat, and a decreased sex drive as a result of the lowered rate of metabolism in the body organs involved. It is quite simple to correct the abnormalities resulting from hypothyroidism. Fortunately, thyroxin is highly resistant to the digestive juices and the hormone may be taken by mouth. Powdered, dried thyroid glands of slaughter house animals may be made into convenient oral tablets and these will contain thyroxin to make up for the deficiency in the body.

The symptoms just described apply to hypothyroidism which develops after a person becomes an adult. If there is a deficiency from birth the symptoms are much more serious because the decreased rate of metabolism during the developmental period of life interferes with growth and results in mental, physical, and sexual retardation. Persons exhibiting this condition are known as **cretins.** A cretin thirty years old may have intelligence no higher than a five-year-old child, he will be dwarfed in stature, and probably sexually immature. If such persons are given thyroid tablets as soon as the symptoms of cretinism appear in childhood, they will be normal in every respect; but if body growth has been completed, improvement will be less marked.

An enlargement of the thyroid gland causing it to swell out into the neck sometimes occurs when the gland apparently tries to compensate for abnormal function by increasing its size. This condition is known as **goiter.** There seems to be a definite relation between the amount of iodine in the diet and the incidence of goiter, for regions of the world that are deficient in this mineral also have a high incidence of goiter. Iodine is necessary for the synthesis of thyroxin, and undersecretion will result if iodine is deficient. The use of iodized salt in such regions of the United States has resulted in a decrease in the number of cases of goiter.

The **parathyroid glands** are four small endocrines, each about the size of a pea, embedded in the thyroid glands. They secrete a hormone, **parathormone,** that regulates the calcium concentration of the blood. This might not seem to be an important function until we learn that nerve and muscle reactions require a certain concentration of calcium in their surroundings for normal functioning. If we remove these glands from a

dog, the calcium level of the blood will begin to drop and within a day or two the animal will show involuntary muscular twitching and eventually convulsions and death. However, the dog can be saved if given an injection of calcium to restore normal functioning of the nerves and muscles. Such a dog in violent convulsions will be wagging his tail happily within a few minutes after the injection.

FIG. 24.8. Cretinism. The three-year old child on the left is stunted both physically and mentally due to a deficient secretion of his thyroid gland since birth. At seven, after four years of treatment with thyroxin, he has lost most of the symptoms of cretinism; and at nine years of age he has become a child of normal body build and mentality.

To test the effect of too much of this hormone, parathormone may be injected into a dog with a normal supply already in his body. This causes the blood calcium to rise, but it does so at the expense of the calcium found in the bones and teeth, causing a weakening of these vital body parts.

Some types of human convulsions may be due to hypofunction of these glands and may be treated with either parathormone or calcium,

or both.   Weakened bones, tooth disintegration, and cyst formation on the bones may indicate hyperfunction.

The pancreas is interesting because it is both a duct and a ductless gland at the same time.   We have already learned that it secretes pancreatic juice which passes through the pancreatic duct to the duodenum. In addition, it secretes an important hormone, **insulin,** that regulates sugar metabolism and storage in the body.   Histological studies of the pancreas explain its dual function ; there are two distinct types of tissue. Many small ducts can be seen lined with secretory cells that supply the pancreatic juice for digestion, but in addition there are small islands of cells having no connection with the ducts.   These are the **isles of Langerhans** which produce insulin.

A person having a deficient supply of insulin develops a condition known as **diabetes.**   Because of the improper sugar metabolism the concentration of sugar in the blood becomes high and is removed by the kidneys so that there will be sugar in the urine.   If the deficiency is great a person may go into a diabetic coma and die unless insulin is administered.   Unfortunately, insulin is destroyed by digestive juices and must be administered by injection.   However, diabetics soon overcome the "needle complex" and can lead fairly normal lives by giving themselves regular injections of this hormone.   They need to learn to regulate the amount of insulin taken to correspond with the carbohydrate intake, for too much insulin will cause insulin shock which is even more dangerous than diabetic coma.

The **adrenal glands** are a pair of small bodies lying just above the kidneys.   If one of these glands is cut in two it will be seen to consist of two distinct portions, an outer bark, the **cortex,** and an inner marrow, the **medulla.**   These portions represent two entirely separate endocrine glands.

The medulla secretes the well-known hormone **adrenalin,** which has several marked effects on the body.   When injected into the body it causes a shrinkage of the capillaries, elevation of the blood pressure, an increase in heart beat, a decrease in blood-clotting time, an elevation of the sugar content of the blood through its release from the liver, and an increased muscular power and resistance to fatigue.   Small quantities are continually being released by this gland, but in times of emotional stress extra quantities are released.   This seems to be a body adjustment which makes us ready for extra activity that may accompany emotional stress : if we are angry, to fight ; if we are frightened, to run ; and so on. Our body is keyed up for emergency action and in case we are injured in the action the blood will clot more readily.   Because of these effects adrenalin is a valuable medical product.   It may restore heart beat when

this organ fails during surgical operations; it will relieve attacks of asthma by shrinking the lining of the air passages, allowing easier breathing. For the same reason it makes breathing easier in colds or hayfever; it may be sprayed on bleeding gums or membranes to hasten clotting after minor operations in the mouth, nose, or throat; it will help bring a person out of insulin shock by releasing sugar into the blood. Because of these and other uses a doctor's kit usually contains adrenalin ready for emergency use.

The cortex of the adrenal gland secretes a number of hormones which are essential to normal life. The first of these to be discovered is known as **cortin.** This hormone seems to regulate the concentration of sodium chloride and potassium in the blood and is related to the conversion of proteins to carbohydrates. When there is an undersecretion of this hormone there is an excessive excretion of sodium chloride, table salt, in the urine and a corresponding deficiency in the blood, but there will be an increase of potassium in the blood. Also, there will be a drop in blood sugar as the conversion of proteins is diminished. This unbalance of substances in the blood may lead to **Addison's disease,** which is characterized by a general body weakness, digestive upsets, and a dark pigmentation of the skin. People with this disease show remarkable improvement when cortin is injected.

More than twenty other hormones have been isolated from this part of the adrenal gland in recent years. This makes it one of the most complex of the endocrine glands. The best known of these hormones is **cortisone** which first reached the limelight when it was found that controlled doses of this hormone relieved many persons who were suffering from arthritis. It reduces the inflammation of the joints and increases the patient's sense of well-being. Since then it has been used to treat many other human ailments which involve inflammation of body tissues, such as hayfever and eye infections, with varying degrees of success.

The hormones of the cortex are closely related to the hormones of the gonads, particularly the male hormone, and they may influence the gonads and other sexual characteristics of the body. Sometimes a tumor will develop on this gland and cause an over-secretion of the cortical hormones. If this happens in a man there will be an increase in his male characteristics. This is particularly noticeable in the excessive hair growth. In a young boy the effect will be a premature development of mature masculine characteristics. In a woman there will be a beard growth, development of male musculature, and a deepening of the voice. The female organs tend to atrophy and become nonfunctional.

The **gonads** are glands that have already been studied under the reproductive system in the role of producers of gametes, sperms, and eggs. Like the pancreas, however, they are dual in their function, secreting hormones in addition to reproductive cells. Since these hormones differ according to sex we will study them separately.

In the male the **testes** secrete the hormone **testosterone** that is responsible for the development of the characteristics that we think of as masculine. If a boy is castrated before puberty the voice will remain at a high pitch, the beard will not grow normally, the muscles do not become masculine, and he will not develop the aggressive personality, nor the attraction toward women, characteristic of normal men.

Hypofunction of this gland will produce undersexed individuals that may be benefited by hormone treatment.

In the female the **ovaries** secrete two hormones. The first of these, **estrogen,** is produced in the follicles containing the maturing eggs. This is the female hormone that seems to be responsible for the development of feminine characteristics. In addition, estrogen plays an important part in the reproductive cycle of a woman. It is produced in greatest quantities in the maturing follicle before ovulation and this prepares the walls of the uterus for the possible reception of the fertilized egg. After ovulation the ruptured follicle changes its appearance and becomes a small yellow body on the ovary. This yellow body is called the **corpus luteum** and secretes the second female hormone, **progesterone.** This hormone seems to effect the final uterine changes necessary for gestation. corpus luteum will remain and continue to secrete its hormone which maintains the uterus in the normal condition for the development of the embryo. It also stimulates enlargement of the breasts during pregnancy. In case there is no fertilization, the corpus luteum will disintegrate and, in the absence of its hormone, the uterine wall will break down, releasing cells and blood in the process of menstruation. Then, as estrogen production increases from another follicle, the uterus again is prepared for reception of a fertilized egg and the cycle is repeated.

Progesterone has great medical value. It may be injected to prevent threatened abortions, since one of its functions is to keep the uterus in condition to retain the embryo. It may also help to relieve the nausea of early pregnancy.

The **pituitary gland** consists of three lobes which have different embryonic backgrounds and secrete different hormones. They are known as the anterior, intermediate, and posterior lobes. The intermediate lobe secretes a hormone, **intermedin,** which exerts an influence on the pigment cells, chromatophores, of fishes, amphibians, and reptiles. The color changes which many of these animals make in response to

their environment result from the action of this hormone. The hormone is also produced in man, but it does not affect his skin color and no other function of the hormone has been discovered.

An extract of the posterior lobe, **pituitrin,** has been found to have three major effects on the body. It causes a constriction of the small blood vessels with a consequent elevation of blood pressure (**pressor action**). It inhibits the loss of fluid through the kidneys (**antidiuretic action**). It stimulates the smooth muscles, especially the muscles of the uterus of the female (**oxytocic action**). It has been possible to separate the extract of the posterior lobe into two hormones. One, known as **pitressin,** affects the blood pressure and the kidneys; the other, known as **pitocin,** has the uterine-stimulating property. This latter hormone is valuable in obstetrics because it gives physicians a method to stimulate uterine contractions during difficult childbirth. When there is a deficiency of pitressin, a person will excrete great quantities of a very dilute urine and will consequently have a great thirst which causes him to drink large quantities of water. This condition is known as **diabetes insipidus,** but it bears no relation to the diabetes mellitus, or sugar diabetes caused by insulin deficiency. Injections of pituitrin or pitressin relieves the symptoms of diabetes insipidus.

The anterior lobe of the pituitary is probably the most important endocrine gland in the body. It is sometimes called the master gland because it exerts controlling influences over other glands of the body. It seems to produce not one, but numerous hormones with various functions. The first of these to be discovered was the **growth hormone.** When this hormone becomes overabundant in a child it leads to unusual bone growth and results in gigantism, whereas dwarfism results from its deficiency. When it becomes overabundant after bone growth has ceased it stimulates bone growth in restricted areas such as the face, hands, and feet, causing a painful deformity known as **acromegaly.**

Later it was found that this gland secreted a **gonadotropic,** or gonad-stimulating, hormone. Young male animals injected with this hormone showed greatly accelerated sexual development and greatly enlarged testes. Male baby chicks developed combs, spurs, and attempted to crow and mate with baby females at the age of six weeks. In the female the hormone serves to regulate the reproductive cycle by stimulating the production of estrogen and progesterone. Unfortunately, this hormone is very unstable and quickly loses its potency in solution, but it has now been prepared in a crystalized form that can be stored and used medically. Infantile sexual organs in a woman and the resulting sterility may sometimes be corrected by injections of this hormone. Cryptorchism, failure of the testes to descend into the scrotum, and similar evi-

dences of under-sexuality in the male may respond to this treatment. It should be kept in mind, however, that the gonadotropic hormone does not directly cause these changes, but stimulates the gonads to secrete the hormones that cause them.

The anterior lobe also secretes a **lactogenic hormone** that is necessary for the secretion of milk in mammals and the associated mother instinct necessary for nursing. By experimental use of this hormone a tom cat has been made to secrete milk and nurse kittens. It may prove useful in subnormal human lactation.

A fourth hormone, the **thyrotropic hormone,** stimulates the thyroid gland to produce thyroxin. Injection of extra quantities of this hormone causes all the symptoms of hyperthyroidism and, if continued, an increase in the size of the thyroid gland.

A fifth hormone, the **adrenocorticotropic hormone,** generally referred to as ACTH, stimulates the secretion of the cortex of the adrenals. It is often used rather than cortisone to alleviate the symptoms of arthritis, since it stimulates a person's own glands to produce more cortisone. Very good results have been obtained with it, but the effects may wear off unless injections are continued. Unfortunately, too much ACTH may lead to disturbed mental conditions and even insanity in a few cases, so it must be used with caution.

A sixth hormone, the **diabetogenic hormone,** seems to decrease sugar metabolism; thus it is directly antagonistic to insulin. Apparently it is the balance between these that keeps the sugar level of the blood normal. When the insulin decreases, this hormone causes the rise in sugar level and diabetes results. Removal of the pituitary in experimental diabetic animals has caused the sugar level of the blood to return to normal.

REVIEW QUESTIONS

1. Tell how the kidneys remove excretory wastes from the blood.
2. Why do we say that frogs are like water animals with respect to reproduction?
3. How do the eggs reach the oviduct in frogs? How does this compare with the method in human beings?
4. How do the endocrine glands differ from other glands in the body?
5. Name the endocrine glands, tell what hormones they secrete, and give the general function of each hormone.
6. If a person having diabetes becomes greatly upset emotionally he may go into a diabetic coma. Can you reason out why?
7. Gonadotropic hormone will cause precocious sexual development in normal young animals, but not if the animals are first castrated. Explain.
8. If the pituitary gland is removed from an animal showing symptoms of diabetes the symptoms will disappear. Explain.
9. Explain how the ducts leading from the kidneys differ in the male and female frogs.
10. What hormones have been beneficial in the treatment of arthritis? Why?

11. How can the inguinal canal be a source of weakness in the human male?
12. Why are men with undescended testes usually sterile?
13. How is progesterone used medically?
14. What is the function of estrogen?
15. What are cretins and how may their condition be alleviated?
16. What is the difference in the cause of gigantism and acromegaly?
17. Describe the structure of the human kidney.
18. What hormone maintains the proper calcium level in the blood?
19. What three systems empty their products into the frog cloaca?
20. Explain the changes brought about in the body by the injection of adrenalin.
21. Distinguish between diabetes insipidus and diabetes mellitus as to cause and symptoms.
22. Why is the pituitary sometimes called the master gland of the body?

25

Aquatic Vertebrates

Cyclostomes and Fishes

The three most primitive classes of the vertebrates contain animals that are aquatic in nature—that is, they spend practically their entire lives in the water and, as a rule, can live only a short time out of the water. In this chapter we will survey some representative members of these classes.

Round-mouthed Eels—Class Cyclostomata

It may seem peculiar that an animal would have a mouth which it cannot close, yet this is exactly what is found in the cyclostomes— the mouths are round and permanently open, for there are no jaws to close them. The marine lamprey eel is a well-known representative of this class. It is a long slender eel-like animal, but it should not be mistaken for the true eel which is a bony fish. The lampreys are com-
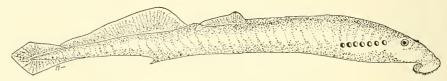
Fig. 25.1. A lamprey eel.

mon along the Atlantic Coast and may also be found in fresh-water rivers and streams where they go to reproduce. Many have gotten into some of our larger lakes, especially the Great Lakes where they now remain as permanent inhabitants. The lamprey has an unusual method of feeding which is very efficient in spite of its lack of jaws. Teeth are present in circles around the sucking mouth and help the animal to hold onto its prey. Teeth are also found on the tip of the firm tongue. When a hungry lamprey attaches itself to the body of a large fish by suction, the tongue is moved back and forth like a saw by very powerful muscles until a hole is cut in the body of the fish. Then the blood and small particles of flesh are sucked into the digestive system of the

parasitic lamprey. The hole which is made in the fish is so large and deep that the fish usually dies as a result of this attack. In the Great Lakes the lampreys have destroyed so many fish that they are believed to be largely responsible for the decline of commercial fishing in that region.

A lamprey has seven pairs of gill openings, which are more than is found in members of other groups of vertebrates. In many ways the lamprey is either primitive or degenerate—it has no paired appendages, there is only one nostril and that is on the top of the head, and there is no stomach, pancreas, or spleen. If we cut into the body of the lamprey we find that there is no bony skeleton, but there is a large notochord which runs the length of the body and serves to help support the softer body tissues. Also there is a basket composed of cartilage which supports the gills, and there are small pieces of cartilage in the head. When ready to reproduce, lampreys swim up into small, clear streams and build nests by moving rocks with their sucking mouths. The females then lay their eggs in the nest, and the males release sperms over them. Many species of lampreys die soon after reproduction, and it is common to see dozens of dead lampreys washed up on the banks of a stream or floating down with the current shortly after the reproductive season.

An egg hatches into a small fish-like creature that looks very different from an adult. In fact, it is so different that it was once classified as a different animal under the name, *Ammocoetes*. This larval stage resembles Amphioxus in many ways and was for a time grouped with it in the Cephalochordata. Then it was discovered that it underwent a metamorphosis after several years and became a lamprey. This resemblance indicates that the lamprey and Amphioxus are probably closely related through a common ancestor.

Cartilaginous Fishes—Class Chondrichthyes

The members of this class have a much better developed skeleton than that of the cyclostomes, but the skeleton is composed of cartilage —there is no true bone. Cartilage is a material which is flexible to a certain degree, but is rigid enough to maintain its shape and support softer body parts. The ear flap of man which projects on either side of the head is composed of cartilage covered with skin. We can bend our ears in various directions, but they go back to their original shape when we release the pressure.

The best known member of this class is the **shark** and we will use it as an example of the group. The shark has a body which shows a

number of distinct advances over the lamprey. It has a **mouth** with movable jaws lined with several rows of sharp teeth. It has a pair of **nostrils** at the front of the head. These are used for the sense of smell only and play no part in respiration. Sharks have a very keen sense of smell and become very excited when they detect the scent of blood in the water. There are five gill pouches on each side of the head and these open to the outside by means of five **gill slits.** Water is taken in through a pair of **spiracles** on top of the head, passes over the gills which line the gill pouches, and goes out through the gill slits. Embryological studies show that the spiracle is homologous to the first gill slit in the lamprey. It is lined with vestiges of gills, but these do not function in respiration.

Photo by Winchester

FIG. 25.2. Tiger shark. This is a splendid specimen of the tiger shark photographed at Marineland aquarium in Florida. Note the small shark sucker attached to the mid-ventral surface of the shark. The shark sucker is not a parasite but merely goes along for the ride and sometimes shares in the food eaten by its huge companion. This is an illustration of commensalism.

A shark bears two paired appendages, one in the shoulder region, the **pectoral fins,** and one in the hip region, the **pelvic fins.** Internally these are attached to the **pectoral girdle** and the **pelvic girdle,** respectively. There is a segmented vertebral column composed of cartilage and vestiges of the notochord. The **brain** is completely enclosed in a cartilaginous skull.

We ordinarily think of **ears** as organs of hearing, but the shark has ears that do not function in this sense. **Balance** is the primary sense which is localized in the ears, and the secondary function of hearing does not appear until the land animals have developed. The shark has a pair of internal ears embedded in the cartilage of the skull. Each ear consists of three pairs of **semi-circular canals** and a central chamber. If these ears are removed, the shark cannot tell whether it is right

side up or upside down. It is just as likely to swim on its back as it is in the more normal position with the back up. The sense of hearing is localized in a row of sense organs contained in a **lateral line** which runs along both sides of the body. These sense organs pick up vibrations in the water.

With respect to reproduction the sharks seem to be quite advanced, for the **young are born alive,** a condition that we commonly associate only with the highest class of vertebrates, the mammals. However, upon closer study, it is found that the sharks have eggs just as the other lower vertebrates, but these are retained in the body until they hatch and the young pass from the mother's body alive and active. We say that animals that lay eggs are **oviparous** and animals that have the young born alive, as the mammals, are **viviparous;** so this condition where they have eggs and have the young born alive also might be called **ovoviviparous.** In any animal in which the young are born alive there must have been copulation and internal fertilization. The median parts of the pelvic fins of the male sharks are modified into **claspers** which aid in this process.

The sharks have a bad reputation because they are often blamed for things done by other water animals. There are large **tiger sharks** found in tropical seas that have been known to attack man, but the cases are not common. Most of the cases of supposed attacks by sharks are actually made by a vicious fish, the barracuda, that has been known to strip the flesh from a person's leg off the southern coast of Florida. The waters of the Atlantic coast contain large numbers of a small shark, the **dogfish shark,** which is quite a nuisance to fishermen because it gets in their fish nets and may damage them with its sharp teeth. The flesh of the shark is not very palatable, but is sometimes eaten and sometimes canned and sold under a trade name so the person buying it will not know that he is eating shark. The oil from the livers is an important source of vitamins A and D.

One of the most abundant sharks found along the waters of the Southern states bordering the gulf is a peculiar form called the **hammerhead shark.** The anterior part of the head spreads out so that it forms a broad extension on either side and the entire animal somewhat resembles a hammer with two driving heads.

The elasmobranchs also include another group of animals called the **rays.** Their general characteristics are about the same as the sharks, but the body shape has been greatly modified. They are flattened out dorsoventrally into a broad fan-like body with a long slender tail. One of these is called the **sting ray** because it has one, or several, sharp spines that project up from its tail. It has a habit of resting on the sand at the

botton where a bather may step on it and receive a rather ugly wound by the sharp, barbed spine, but it does not inject poison and, therefore, is not in the nature of a sting. The **electric ray** possesses organs in its body that actually generate electricity and when disturbed can give a powerful shock to any intruder on its privacy. The **sawfish** has an extension from the front end of the head armed with sharp spines on either side that make it resemble a saw. A sweeping side stroke of this saw could repel any enemies that might be rash enough to disturb this animal.
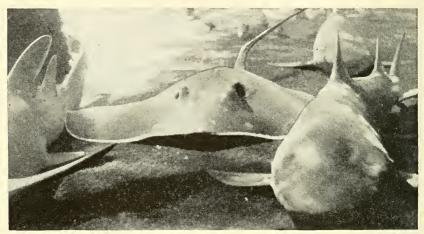
Photo by Winchester
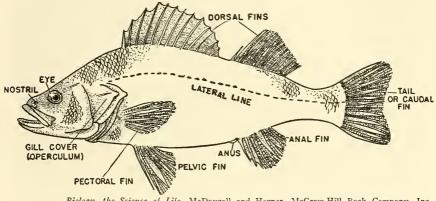
FIG. 25.3. The sting ray. Note the long tail which bears the spine that gives this ray its name. This specimen is resting on the bottom of the Marineland aquarium along with several sharks.

Bony Fishes—Class Osteichthyes

The word "fish" is rather loosely applied to almost any kind of animal that lives in the water, but, strictly speaking, it applies only to members of this class. An external examination seems to indicate that there is only one pair of gill slits, but it appears this way because there is an **operculum,** or gill cover, that covers the real gill slits which lie underneath. Upon raising the operculum it will be seen that there are actually four pairs of gills with five pairs of gill slits. There is a **lateral line** as in the sharks. The bodies of most fish are covered by **scales** which overlap like shingles on a roof. A close examination of these reveals that they bear concentric rings of growth similar to those found on the shell of a clam. The **pelvic fins** of the fish have **moved anteriorly** to occupy a position near the center of the body or, in some forms, just

under the pectoral fins. Internally, this is accompanied by a complete **disappearance of the pelvic girdle.**

The skeleton is **composed of bone,** a fact which hardly needs mentioning since everyone who has eaten fish knows this fact from experience. Another noteworthy internal structure is the **swim bladder,** an air-filled bladder in the dorsal region of the body cavity which serves to make the fish more buoyant. By regulating the amount of air in this sac the fish is able to maintain itself at a desired level in the water. In some fish this bladder has a connection with the pharynx, and air can be gulped down into it. In these forms it serves as an accessory organ of respiration, for oxygen can be absorbed through its walls when the oxygen
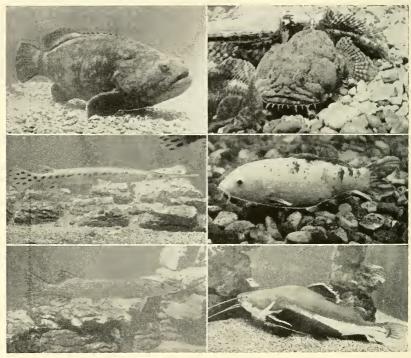
Biology, the Science of Life, McDougall and Hegner, McGraw-Hill Book Company, Inc.
Fig. 25.4. External features of a fish.

content of the water is reduced. The alligator gar is such a fish, and observation shows that it can live in foul water long after other fish have died due to lack of sufficient oxygen. The swim bladder, thus, has a significance as a possible forerunner of the lungs of the land vertebrates.

Protection among Fish. Life in the water is rugged and dangerous; murder and starvation are found on every hand; it seems as if every animal is trying to eat every other animal that is small enough to go in its mouth. There are numerous methods of protection used by fish in an effort to survive under such conditions. One of the most universal is **protective coloration.** Fish are so colored that they are hard to see in their natural environment. The dorsal surface is colored darker than the ventral surface. An enemy swimming over them would see them against the dark bottom of the body of water, but while swimming under them would see the light under surface of the body outlined against the light upper surface and sky and could overlook them in either case.

This condition has probably been developed through the principle of natural selection, discussed more fully in Chapter 34, and the flounder or sole shows that this is not just accidental. This fish spends much of its time lying on its side against the ocean floor and when it is swimming it even swims on its side. The side which is usually underneath, left side, has become light colored, whereas the side which is
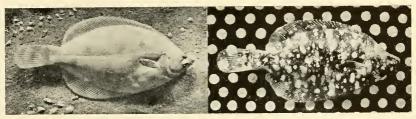
Photos by Winchester

FIG. 25.5. Varieties of fish. From left to right and top to bottom these are: Spotted jewfish, *Promicrops itaiara;* Toadfish, *Opsanus tau;* Long Nosed Gar, *Lepisosteus osseus;* Singapore Carp, *Cyprinus carpio;* Pike, *Esox lucius;* and Red Tailed Catfish, *Phractocephalus hemilopterus.*

usually exposed to light is darker. Curiously enough, the left eye, which was formerly on the left side in a normal position, migrates through the skull during embryonic development and comes out on the right side along with the right eye. An eye pressed into the dirt on the ocean floor would be of no value, but in this unusual position it can function.

Some fish can even change the color and pattern of their bodies to blend with their surroundings. The flounder is another good example of

this; if placed on sand the specks on its body will be quite small, but if placed on gravel the specks will be larger to blend with the larger rock particles. One was placed on a black and white tile and actually developed a rough pattern of checks corresponding in size to the tile. This is possible because of the presence of small color bodies in the skin which can be expanded or contracted to make any area of the skin dark or light.

Many small tropical fish show brilliant coloration and when seen in a fish bowl or aquarium might appear quite conspicuous. However, when seen in their natural surroundings of brilliantly colored coral, seaweed, and other tropical forms of life, they blend nicely and the brilliant coloration is a protection.

Photos by Winchester

FIG. 25.6. Protective coloration in the flounder. The flounder is able to change the pattern and coloration to blend with its surroundings by expanding or contracting pigmented bodies in the skin. Even when placed on such an unnatural surface as that on the right it is able to change until it rather closely resembles its surroundings.

In one group of marine fishes the paired fins are enlarged and may be used in gliding through the air over the surface of the water. These are the **flying fish,** but since there is no flapping of the fins they are actually gliders rather than fliers. When an enemy goes after them they swim rapidly to get a start and then flip themselves out of the water and sail through the air for distances as great as an eighth of a mile.

Another interesting means of protection is found in the **electric eel.** This large eel, which grows to a length of several feet, is found in South American rivers and lakes. When irritated, it is capable of giving out a shock that will knock down a person standing in the water nearby. Wires can be run from one of these eels to an electric light bulb and when the eel is disturbed the bulb will light up.

The **porcupine fish,** found in tropical waters, does not need any of the means of protection described. Its body is covered by sharp spines, which normally lie flat on its body, but when in danger the fish will inflate itself with either water or air so that it expands into a tight ball and the spines stand out to discourage any animal that might wish to eat it. If a large animal, such as a shark, should be so hungry that it swallowed

it anyway, it is just too bad for the shark. The porcupine fish secretes a red fibrous material around itself, which protects it from the digestive juices of the shark, and then calmly proceeds to eat its way through the shark's stomach and into the water outside, none the worse for its experience.

Fish Reproduction. The reproductive habits of fish show great variation in the number of eggs and the degree of care or protection given to the eggs and young. It is a general rule of nature that these two factors are in inverse proportion to one another. At one extreme, we find fish, like the **sturgeon,** that deposit the eggs broadcast in the water and the sperms are released in the same way. The fertilized eggs sink to the bottom and receive no protection of any kind. As a result they are eaten by many animals so that few of them ever hatch and many of the young that do hatch are eaten before they can mature. The sturgeon is able to compensate for this great destruction by laying an enormous number of eggs. A female will lay approximately three million eggs each year for about ten years, or a total of about thirty million eggs from one female. From this huge number only two, on the average, will survive and live to reproduce, one male and one female. Even man is numbered among the animals that eat the sturgeon eggs, for caviar is made from sturgeon eggs. Much of our caviar comes from the paddlefish, or spoonbilled catfish, a relative of the sturgeon, which is common in the southern Mississippi River.

At the other extreme are quite a number of ovoviviparous fish, such as our common **fresh-water minnow,** Gambusia. As in the sharks, this little fish retains the eggs in its body until they hatch and the young are born alive so that they have a chance to swim away from their enemies from the first. The anal fin of the male is modified into a long slender tube which serves as a copulatory organ in transferring sperms to the female. A much smaller number of eggs is formed and there may be no more than a dozen young minnows produced at one reproductive cycle.

The **fresh-water catfish** is somewhere in between. These fish scoop a nest out of the mud along the side of the river in which they live and the female lays the eggs in the nest and goes on her way. The male will release sperms over the eggs and stay around waving his fins near them to keep a fresh current of water flowing over them so that they will receive plenty of oxygen. He will protect them with his life and, although the catfish is normally a rather sluggish animal, he is very active and aggressive if any other animal threatens injury to the eggs. When the young hatch he will stay with them for a time and he may even open his mouth so that the young can swim inside for safety when there is danger. This illustrates an interesting principle of fish reproduction. We are ac-

customed to thinking of care of the eggs and young as a maternal in-
stinct, but in the fish it is the male that gives the care to the young if any
is given.   The female shows no further interest in the proceedings after
she has laid her eggs.

Photo by Winchester

Fɪɢ. 25.7.   Male sea horse with brood pouch. If any care is given the young in fishes
the male does it.   In the sea horse the male develops this large pouch on the ventral
surface of its body and places the eggs from the female in it to hatch.   It also serves
as a place of protection for the young after hatching.

The **sea horse** is one of the strangest of a host of strange fish in
respect to reproduction.   The name is not descriptive of size for it is
seldom more than five inches in length, but the head does somewhat
resemble the head of a horse.   The male sea horse has a brood pouch
located on the ventral surface of the tail and, during the reproductive
season, he will swim behind a female and, as she lays the eggs, he will
catch them in this pouch.   As he swims around in an upright position

with his pouch distended with eggs, he looks very much like a pregnant animal about to give birth to offspring. It is sometimes said that this is the only species of animal in which the male becomes pregnant. When the eggs begin to hatch the male will hold onto a twig with his tail and appear to go through all the pangs of labor as he brings forth the living baby sea horses from his pouch.

The **Pacific salmon** has one of the most complicated reproductive cycles of them all. The adults are found in salt water, but they never reproduce there. When they are ready to reproduce, which is at about seven years of age, they will go into one of the fresh-water rivers that empty into the Pacific. They are one of the few fish that are able to make the transition from salt to fresh water without fatal reactions. They continue up the river until they reach shallow spring-fed streams far inland in which to spawn. The remarkable part about the whole process is that they return to the identical stream where they were hatched seven years previously. This can be determined by marking the young salmon and checking their return. As they proceed up the river they come to many forks and turns, waterfalls and rapids, but nothing can stand in the way of their return to their place of origin. When we are returning from a drive in the country and forget whether to take the left hand or the right hand road when we just passed there a short time previously, we can appreciate the salmons' problems in making their way back.

During their journey upstream they take no food and their mouths become modified for digging their nests so that they could not eat if they wanted to. Upon arriving at the breeding places they dig a nest over a spot where a spring is bubbling up through the gravel, for such a spot will not freeze during the severe winter which is found in northwestern United States, western Canada, and Alaska. The eggs are then laid, the sperms released over them, they are covered with gravel and the parents flounder around awhile in the shallow water and die. The wolves and vultures then have a feast, but the flesh is tough and stringy and not fit for human consumption after the long exhaustive journey which the salmon have made. They are caught in salt water for canning just before they enter the rivers or shortly after they enter. When the young hatch the following spring they slowly make their way downstream and reach the ocean about a year later.

Classification and Derivation of Scientific Words

Subphylum Vertebrata (Cont.)

    Class A. Cyclostomata (Gr. *cyclos,* circle; *stoma,* mouth; refers to the shape of the mouth). Lamprey eel.

Class B. Chondrichthyes (Gr. *chondros,* cartilage; *ichthys,* fish; the skeleton is made of cartilage). Sharks, rays, skates.

Class C. Osteichthyes (Gr. *osteon,* bone; *ichthys,* fish; the skeleton is made chiefly of bone). Sturgeon, lungfish, perch, salmon.

REVIEW QUESTIONS

1. Explain the feeding habits of the lamprey eel and tell what these habits have to do with commercial fishing.
2. What evidence indicates a close relationship between the lamprey eel and Amphioxus?
3. What is the function of the lateral line of fish?
4. What is meant by ovoviviparous reproduction?
5. Describe the two functions of the swim bladder.
6. How does the flounder change its color pattern to blend with its surroundings?
7. Discuss protection of the young in fish.
8. Would you think that the sea horse would lay as many eggs as the sturgeon? Give reasons for your answer.
9. Describe the reproductive cycle in the salmon.
10. What is the function of the internal ear of the fish?
11. Describe the so-called "flight" of the flying fish.
12. How does the freshwater minnow, *Gambusia,* fertilize its eggs?
13. Tell the methods of protection used by the sting ray, sawfish, and electric eel.
14. What is the function of the notochord in the lamprey?
15. What is the function of the spiracle in the shark?

26

The Transition to Land

Amphibians and Reptiles
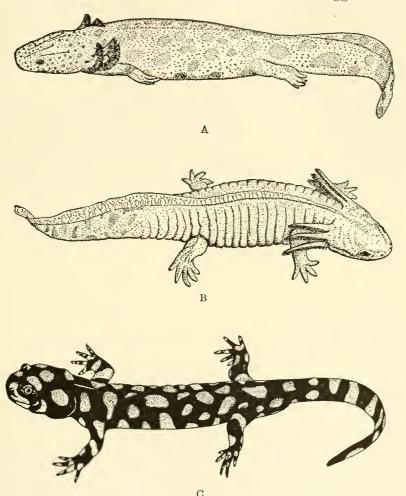
As we learned in the last chapter the first three classes of vertebrates are water animals. The transition to life on the land, such as is characteristic of most of the advanced vertebrates, is not accomplished completely in any one animal, but through a series of adaptations extending over two classes. These two classes of vertebrates will be studied in this chapter.

Class—Amphibia

This class includes the frogs, toads, and a few primitive, tropical, worm-like forms. The class name comes from Greek words meaning **both forms of life,** and animals of this group are given such a name because they really lead a double life ; they are both water and land animals. All the vertebrates studied up to this time have been water animals and the amphibians start their life as if they were going to keep up the tradition. They hatch out of the egg as fish-like animals with three fully developed and functional gills which are used for respiration. After a time, however, certain changes occur which transform them into animals adapted to live on the land. The gills gradually disappear and lungs appear, small limb buds appear which grow into legs, and a neck appears to give the head movement independent of the trunk. These animals are now able to crawl out on the land and take their place as terrestrial vertebrates. Some of them have made quite a success of their life on land, while others seem to have found this life too rigorous and have crawled back in the water to spend the greater part of their time there, even though they must come to the surface to breathe. A few of these do not give up their larval gills and use both gill and lung respiration.

In making the transition to land, however, the amphibians have retained some of the methods of living characteristic of aquatic animals. Although some of them are capable of living on the land far from the water, when the time comes for reproduction they must return to their ancestral home in the water to accomplish this vital function. There

are two reasons for this. First, the male has no copulatory organ to be used for the transference of sperms into the body of the female, as do most land vertebrates. Second, the amphibians have an egg which can-

A

B

C

FIG. 26.1. Salamanders. A. The mud puppy, Necturus. B. The larva of the tiger salamander, Ambystoma. C. The adult of the tiger salamander, Ambystoma.

not survive away from the water. To live and grow on the land, an egg must have a thick, protective shell, and the embryo must develop special membranes inside the shell to take care of respiration. Since the amphibian egg has neither, it must develop in the water. Amphibian eggs

are surrounded by a mass of transparent jelly, however, which protects them to some extent in the water, but it dries up quickly on the land.

There is one group of amphibians which retain the tail as an adult. These are commonly called the **salamanders** or **newts.** Some of these live almost entirely in the water and may keep their gills throughout life, but they also develop lungs and use both gill and lung respiration. Others live mostly on the land, but are not as well adapted to life on the land as the toads and they must crawl under rocks and logs during the daytime to prevent their skin from drying.

The common **mud puppy** (*Necturus maculosus*) is a large river salamander which retains its gills throughout life. Since it is found in large rivers which do not dry up in the summer, this is a useful adaptation. It is a fearsome-looking creature, and many fishermen think that it is deadly poisonous. Many will not touch one if they happen to catch one on their line. Actually, it has teeth so tiny that it is incapable of inflicting a bite that will break the skin on man. Mud puppies are regularly dissected in courses in comparative anatomy and, for this reason, the demand for them is very great.

The **mud eel** (*Siren*) is another interesting salamander which keeps its gills throughout life. It has a long, slender, eel-like body with tiny front legs, but no hind legs. It is nearly helpless on land, but in the water it can swim with undulating movements of the body with the front legs folded back against the body. At rest, however, the front legs help this peculiar salamander to keep upright and to walk around slowly. Evidently, in the distant past a mutation or series of mutations of the genes resulted in the loss of the hind limbs; and the species survived as well, or perhaps even better, without them, and this characteristic became established in the species. Hind legs might interfere with the smoothness of the body when the mud eel was trying to escape from an enemy.

The **Colorado axolotl** is a very interesting species which is found abundantly in the mountain streams of Colorado. Like all amphibians, the larvae have gills. There is no metamorphosis, however, and the gills are retained throughout life. It is sometimes said that they remain larvae in general body structure, but become sexually mature. In other regions there is a tiger salamander (*Ambystoma tigrinum*) which looks just like the Colorado axolotl as larvae, but they undergo metamorphosis and become spotted adults without gills. When some of the Colorado axolotls were taken east they soon changed color, lost their gills, and crawled out of the aquarium as typical tiger salamanders. It was discovered that absence of iodine in the water of the mountain streams

Fig. 26.2. A tiger salamander, *Ambystoma tigrum*.

was the cause of the failure of the axolotl to metamorphose. The addition of a little iodine to the water of an aquarium or, better still, the feeding of fresh thyroid glands to the axolotls causes them to become land salamanders even though they stay in Colorado.

Strange to say, salamanders have internal fertilization even though they have no organs for copulation. The male and female first go through a courtship "dance" in the water, then the male deposits packets
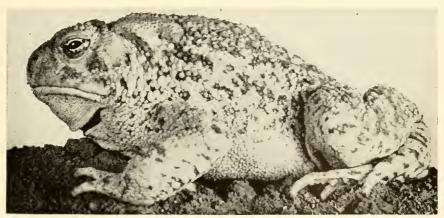
Fig. 26.3. A toad. From this photograph it is easy to see where we got the expression "puffed up like a toad." The warty skin also shows where we got the superstition that handling toads would cause warts on the hands.

of sperms (spermatophores) on leaves or other objects in the bottom of the pond. The female comes along behind him and picks them up with the lips of her cloaca. The sperms are stored in special organs in her body. Later when she lays eggs some of the sperms are released and fertilize these eggs as they pass through her cloaca, although by this time the male may be far away.

Amphibians that lose their tails as adults are either **frogs** or **toads.** The toad lives more as a land animal than the frog and has developed a dry, warty skin. It is sometimes thought that a person may get warts by handling a toad because of their presence on the toad's skin, but there is not the slightest foundation for such belief. The eggs of toads may be distinguished from those of frogs when seen in the water. Toad eggs are laid in a long string and look somewhat like beads on a string, while frog eggs are laid in a gelatinous mass. The frogs have been discussed in Chapters 22–24 as typical chordate animals.

Class—Reptilia

The transition from water to land habitat, started by the amphibians, is completed by the reptiles. This has been accomplished by the development of a copulatory organ in the male and the development of an egg that can hatch on the land. Also many changes in other body organs have come about as an adaptation to life on the land. Like some amphibians, there are reptiles, such as turtles and crocodiles, that spend
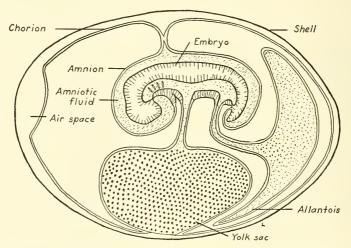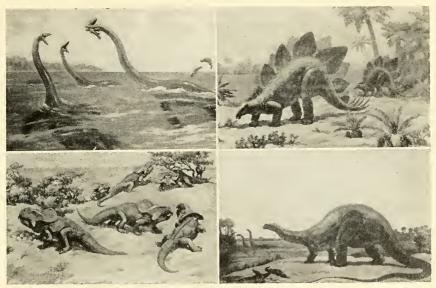
Fig. 26.4. The developing embryo of a reptile or bird. Note the large yolk sac which supplies food to the developing embryo and the allantois which takes care of respiration.

a great part of their time in the water, but they are typical land animals and some reptiles inhabit some of the most arid regions of the world.

The water egg of fish or amphibians consists of an outer membrane containing the developing embryo attached to a yolk sac for nourishment. The land egg of reptiles or birds must have a thick, protective **shell** on the outside. This shell may be tough and leather-like, as in the reptiles, or brittle as in the birds. Beneath the shell another membrane is devel-

Paintings by C. R. Knight in Chicago Natural History Museum

FIG. 26.5. Reptiles of the past. Modern reptiles are but a small remnant of the great number that once dominated the earth. These pictures show four of the prehistoric forms in habitat scenes as worked out from fossil remains. From left to right and top to bottom they are: Plesiosaurus, swimming lizards; Stegosaurus, the armored dinosaur; Protoceratops, one of the smaller dinosaurs; and Brontosaurus, the thunder lizard, largest of the dinosaurs.

oped, the **allantois,** which is necessary for respiration. This membrane is supplied with many blood vessels from the embryo and the circulating blood absorbs oxygen through the porous shell and releases carbon dioxide. The embryo is surrounded by another membrane, the **amnion,** which contains the amniotic fluid, in which the embryo floats. Thus, it is evident that the embryos of land animals develop in a liquid medium after all, even though the egg remains on the dry land. The exact relationship of these membranes is shown in Fig. 26.4. Reptile's eggs do not need to be incubated, since they are cold-blooded animals, so they are usually buried in the ground and left to hatch.

Prehistoric Reptiles. At one time, reptiles were the dominant animals of the earth.   There were the huge land dinosaurs, that were much larger than any land animal of today, as well as many smaller land reptiles that dominated life on the land.   There were flying reptiles that were abundant in the air and tremendous swimming reptiles that were extremely abundant in the waters of the earth.   Through studies of prehistoric and modern reptiles, we have been able to identify 125 families in this class. Of this great number, however, only eighteen are found alive on the earth today.   These show particular adaptations that enabled them to survive while their many relatives became extinct.
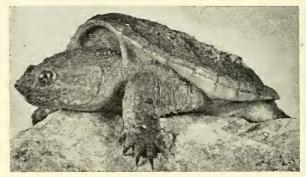
Photo by Winchester

FIG. 26.6.   A snapping turtle.   This turtle looks rather sluggish but it has a reputation for quick action as it snaps for food or a finger that might be held too close.

The decline of the reptiles was accompanied by a rise of the mammals. There are a number of theories to account for this change of emphasis in the animal world but one of the most plausible is based on climatic changes which are known to have occurred in the past.   It is known that the climate of the United States, for instance, has varied from tropical to frigid during past geological eras.   Reptiles are cold-blooded animals and may be quite active in warm weather, but when the temperature drops their muscles become sluggish in their movements and they become entirely inactive when it gets down around 45 degrees or below.   A rattlesnake placed in a refrigerator becomes quite harmless until he gets warmed up again.   The opposite is true of mammals; they may feel sluggish in very warm weather, but as the weather becomes brisk they become more and more active.   During tropical climatic periods the reptiles could dominate the mammals, but as the weather got cool small aggressive mammals could easily overcome the larger and stronger reptiles and exterminate many of them.

Turtles.   These reptiles have traded activity for protection.   They are slow and awkward, but so well protected by their outer "shell" that

they have been able to survive while their more active relatives became extinct. Although amphibians typically have a smooth skin, the reptiles have **scales** on their bodies. In this group of reptiles some of the scales have become greatly enlarged, thickened, and fused together to form the "shell." In many turtles this is hinged so that the head and legs may be drawn inside and the "shell" tightly closed. Land turtles are usually referred to as tortoises, while the name turtle is commonly used when referring to those that live primarily in the water. Turtles hold the world's record for holding their breath under water, for they have been known to stay submerged for as long as three hours without coming up for air.
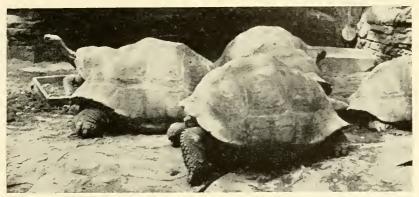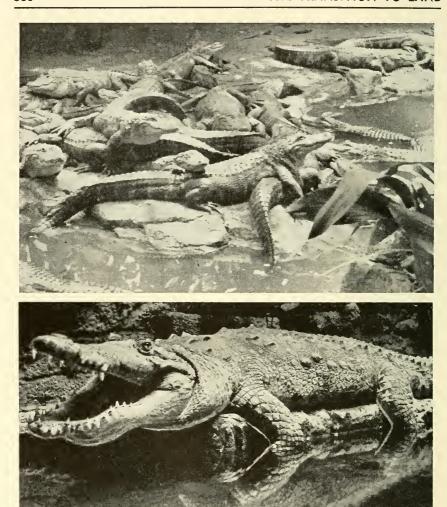
Photo by Winchester

FIG. 26.7. Galapagos tortoises. These huge reptiles, living on the Galapagos islands, where enemies are few, often live to be several hundred years of age. This group is kept at the Brookfield Zoo in Chicago.

On the Galapagos Islands there are huge tortoises weighing several hundred pounds and estimated to be up to four hundred years old. They are probably the oldest living animals on the earth.

Crocodiles and Alligators. These are the giants of the living reptiles; they frequently grow to a length of twenty feet and have actually been measured thirty feet long. Their huge bodies, armed with powerful jaws lined with sharp teeth, make the crocodiles antagonists to be respected by any living creature. They are always found in or near large bodies of water. They may often be seen sleeping on the bank of a tropical river, but on being disturbed they plunge into the water where they are undisputed masters. At other times they float lazily near the surface, with just their nostrils, eyes, and the upper parts of their heads above the water. In this position they look very much like floating logs.

There are only slight differences in the crocodiles and alligators, but the crocodile seems to be the more vicious and aggressive of the two.

Photos by Winchester

Fig. 26.8. American alligator above and American crocodile below.

Fortunately, the alligator is the one most abundant in the coastal regions of the southern states, although there is one species of crocodile in Florida. The crocodiles infest rivers and lakes in tropical regions all over the world and are especially abundant in the rivers of Africa.

Lizards. The lizards are an extremely varied group of reptiles adapted to a wide range of environments. They range from tiny worm-like burrowing forms to those more than twelve feet long with long sharp claws, able to tear their prey apart like a tiger. They are one of

the few animals that are able to exist on the hot, dry, sandy deserts, but they are also found in moist forests and even swimming in the water. Some move so swiftly that they appear as a streak to the eye; others move so slowly that they seem to be in slow-motion movies. Some have well-developed limbs; some have none at all and may be mistaken for snakes.

Many lizards, at one time or another, are accused of being poisonous, but there is only one species in the United States that deserves this accusation. This is the **Gila monster**; it is a clumsy, thick-bodied lizard with

Photo by Winchester

FIG. 26.9 A Gila monster. This is the only poisonous lizard in the United States. Its poison sacs are in the lower jaw and grooved teeth carry the venom into an animal that is bitten. Although it looks and acts like a sluggish creature it is capable of rapid movements accompanied by snapping jaws that cause it to be respected.
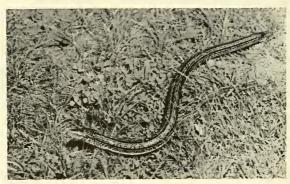
Photo by Winchester

FIG. 26.10. Texas horned lizard. Its appearance in such a close-up view reminds one of the ancient dinosaurs.

a heavy tail that acts as a food reservoir to tide it over periods of food scarcity. It is found primarily in Arizona and is especially abundant along the Gila River. It moves awkwardly but, when molested, is capable of quick movements of the head accompanied with a snapping of the jaws which may easily fasten onto a hand held too near. Gila monsters have grooved teeth with poison glands at their base and once they have fastened their grip they hold on for a time, chewing a little to work the poison down into the wound. The bite makes a person quite ill, but the poison does not seem to be injected in sufficient quantities to cause death.

The **horned lizard** of Texas and other southwestern states has an appearance that would make it look like some prehistoric monster if it were much larger. It has a broad flattened body resembling that of a toad
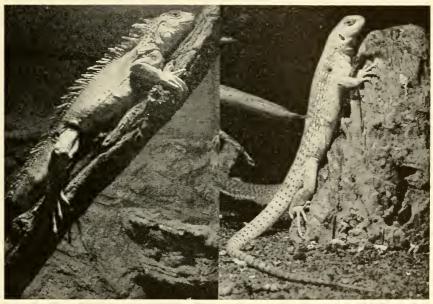
R. Marlin Perkins, Chicago Park District

FIG. 26.11. The glass snake or the jointed snake. This reptile is not a snake at all, but a legless lizard. Like many lizards it will throw off portions of its tail when excited.

and is often called a horned toad. When disturbed it may shoot a fine stream of blood out of its eyes for a distance of several feet. This does not seem to accomplish any particular purpose except that it might startle an attacker and give the lizard a chance to escape.

The **American chameleon** (*Anolis carolinensis*) is very common in the southeastern United States. It is another one of those animals that can alter their color. It has a basal pigment of green in the skin, but over this there are chromatophores of brown which are capable of expansion and contraction. When they are expanded they mask the green and the animal is brown, but the green shows when these bodies are contracted. The color changes come about in response to a hormone from the intermediate lobe of the pituitary gland. When this gland is removed the chameleons remain green—the hormone is necessary for the expansion of the brown chromatophores. It is commonly believed that these ani-

mals will change color to match the color of the object upon which they are resting, but experiments show that this is not true. They frequently stay brown when placed on a green background and vice versa. However, they will respond to the color of light which strikes them. In their natural surroundings these chameleons will be green when light filters down through green foliage, but when they crawl out under the open sky, they may turn brown even though they are resting on a green leaf. During breeding, feeding, and other forms of excitement they are nearly always green. The males sometimes puff out their throat which is a beautiful shade of pink when thus extended.
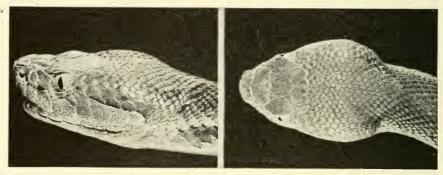
Photos by Winchester

FIG. 26.12. Iguanas. At left, one of the green iguanas found in Central and South America. They often weigh as much as thirty pounds and are used extensively for food. At right, the desert iguana found in western United States is small, weighing no more than a pound or so at most.

The **glass snake** is worthy of mention because it has given origin to the superstition that snakes sometimes become unjointed in times of danger, only to reassemble themselves and crawl away whole when the danger is past. This is not a snake at all, but a legless lizard. Like many lizards it is able to throw off a part of its tail when greatly excited. This is a protective measure; if it is being pursued by an enemy the tail will most likely be caught first. The tail may be broken off and the main part of the lizard escapes while its enemy is satisfied with the tail.

If the tail is thrown off during the chase, it will attract the enemy because it will wiggle actively for a time after being thrown off. The glass snake often does this and the rest of the superstition was pieced together from this one fact. A new tail will be regenerated, but it will require several months to be completed.

Snakes. The mere mention of this word is enough to send shivers down the spine of many a person that has heard so many weird snake tales that he almost thinks of these creatures as being supernatural. There is probably no single group of animals on the earth more feared than the snakes, yet an objective study of their habits shows that they are not deserving of such a bad reputation. The fear is not inborn, as some think, for a child will not show this unnatural fear unless he sees such reactions among his elders and hears the many wild superstitions

Photos by Winchester

FIG. 26.13. Pit viper head characteristics. This head of the copperhead shows the elliptical or slit-like pupil of the eye, the pit anterior and slightly ventral to the eye, and the arrow-shaped head characteristic of the pit vipers.

that some people seem to take delight in repeating. As a whole, snakes are highly beneficial to mankind, for they destroy great numbers of rodents, which are among our worst enemies. A farmer who wantonly chops the heads off the snakes that he finds on his farm is doing himself great harm, for the rodents which these snakes would have eaten will do great damage to his crops and stored grain. Some wise farmers collect large bull snakes and turn them loose in the barn to keep down the rodent population.

Unfortunately, there are some snakes that have fangs connected to poison sacs and are capable of inflicting a poisonous bite, which in some cases may be venomous enough to cause the death of a human being. In spite of whatever benefit they might be otherwise, such snakes are undesirable members of the earth's population and should be destroyed

in areas of human population. However, they make up only a small proportion of the total number of snakes in the world, and it is certainly not fair to condemn an entire group of animals just because there are some undesirables in their midst. It is much more sensible to learn which are not desired and destroy those and preserve the others which are of value.

It is easy to learn the poisonous snakes in the United States, for there are only four types that can bite a person, and these have easily recognized characteristics. Three of them are **pit vipers** which take their

Courtesy Ross Allen's Reptile Institute

FIG. 26.14. Milking a rattlesnake. This large rattlesnake is having its venom extracted at Ross Allen's Reptile Institute in Silver Springs, Florida. Venom collected in this manner is used in producing antivenin serum.

name from the pit which lies just anterior and ventral to the eye. Also, the pupil of the eye is slit-like, such as the pupil of a cat's eye, rather than round, as is found in the other families of snakes. Some are perhaps thinking that it does no good· to know what kind of eye the pit vipers have because they are not going to get close enough to see the pupils anyway. However, it is perfectly safe to get near enough to see the pupil clearly, for the snake will not attack a person and they can strike no farther than half their body length. The third characteristic of the pit vipers is the arrow-shaped head, caused by an enlargement of the head at its junction with the neck. Other snakes may show this

character to some extent, but it is quite distinctive in the pit vipers.   In-
dividual characteristics of the pit vipers found in the United States are
as follows.

The **rattlesnakes** are by far the most abundant and important of the
poisonous snakes in the United States.   They are nervous, tempera-
mental snakes that are quick to strike and carry a very potent poison.
These snakes are best known by the rattle which consists of a series of
rings of dried skin on the tip of the tail.   When a person gets excited
and nervous his hands often tremble; snakes do not have any hands, so
their tails tremble when they are excited.   When the tail trembles at
high speed the rattle makes a characteristic whirring sound that is easily
recognized after it has once been heard.   When the skin is shed a ring

Photo by Winchester
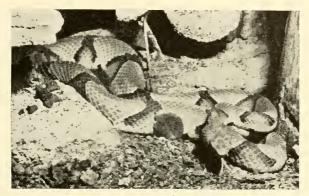
FIG. 26.15.   Rattlesnake poison.   This innocent looking pile of crystals, about a half
an inch in diameter, contains the crystallized poison extracted from thirty rattlesnakes.

of the posterior part of it is left behind to form a ring of the rattle.   It
is sometimes said that a rattlesnake's age can be told by the number of
rings on the rattle.   This is not accurate, for the snake may shed its
skin from one to three times a year and the rings are sometimes broken
off.   Another superstition holds that a rattlesnake always rattles before
striking.   They rattle when they get excited but if you suddenly step
on one that may be sleeping it will strike immediately without waiting
to rattle.

The fangs are long and curved and fold back against the roof of the
mouth in a sheath of skin when not in use.   When danger threatens the
snake will probably try to get away first, but if pressed closely will pull
itself into loose loops facing its foe ready to strike.   As the snake strikes,
the lower jaw is dropped down, the fangs become erect, and the head hits
with enough force to drive the fangs into the flesh.   At the moment they
enter, the poison sacs contract and inject the poison and the snake jerks
its head back ready to strike again.   All of this takes place with light-

ning-like rapidity. The poison is a blood poison and begins destruction
of the elements of the blood. When properly treated most cases of
poisonous snake bite recover. The rattlesnakes account for about 90
per cent of the deaths from snake bite in the United States.

There are about fifteen species of rattlesnakes in the United States.
There are some, such as the little pigmy rattlesnake, or ground rattle-
snake, that have only a single button on the tip of the tail and this does
not rattle. The eastern diamond back rattlesnake grows to the greatest
length, sometimes seven feet. The Texas diamond back rattlesnake is
also a large member of this group.

Fig. 26.16. Southern copperhead snake.

The **cotton-mouth water moccasin** is a dangerous and feared snake of
the swamps and bayous of the southern states. It has the pit viper char-
acteristics and can also be recognized by its dull, irregular, olive brown
color and its thick, heavy body. These moccasins are found in and
around water at all times and, like the rattlesnake, they prefer to escape
danger rather than face it. When approached they may be seen to slip
silently into the water and swim away, but when cornered they are quite
vicious and there are some deaths from the bite.

The **copperhead** is the third and final member of the pit viper family
in the United States. It is a smaller snake than the other two and has
a much better disposition. In fact it is so gentle that it seldom bites
unless it is stepped on, and it certainly cannot be blamed for that. Cop-
perheads have pretty copper-colored bands of irregular shape on their
slender, graceful bodies that make them beautiful snakes. They are not
more than three feet long and do not seem to inject enough poison to
cause death in a normal, healthy person, but it is enough to make a

person quite sick, so first-aid treatment should be given following their bite.

Another very beautiful snake, the **coral,** is the fourth and final venomous one found in the United States. It is not a pit viper; it has a round pupil, there is no pit, and the head is not puffed out where it joins the body. However, it can easily be recognized by the glossy red and black bands, bordered by smaller yellow bands that run around the body. Corals are very gentle snakes, like the copperheads, and the author knows of two cases where they were mistaken for the harmless king snake and were picked up and handled for quite some time before the handlers realized they were dealing with a poisonous snake. Nearly all bites are received when it is stepped on. The coral is a member of the
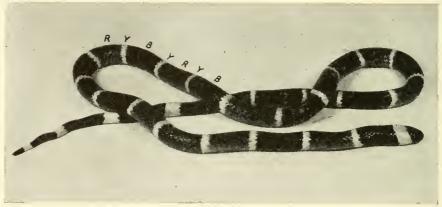
Photo by Winchester

Fig. 26.17. A coral snake. This beautiful little snake has a highly potent poison. It is related to the cobra, with short erect fangs, and must bite, rather than strike, to inject its poison. It is not vicious, and comparatively few people in the United States are bitten by coral snakes. The letters indicate the sequence of the red, yellow, and black bands around the body.

cobra family and this family has short erect fangs, rather than the long retractible fangs like the pit vipers. Therefore, it does not strike, but actually grabs the skin with its mouth and forces the fangs through the skin with a biting motion. Ordinary trousers seem sufficiently thick to protect the legs from its bite. The coral is small, seldom more than eighteen inches long, slender and does not inject enough poison to cause death in most cases. It has a nerve poison that works differently from the pit viper poison that destroys the blood. A person that is bitten may go blind temporarily and have difficulty in breathing and carrying out the other body activities controlled by the nerves.

Death from snake bite in the United States is very low, only twenty to thirty per year, which is almost nothing in comparison with the forty to fifty thousand that die from automobile accidents; but in tropical countries deaths are much more frequent. There are many thousands of deaths in India from the bite of the **hooded cobra**. This interesting snake, when alert, spreads the ribs at the anterior part of the body to form the hood. It often goes into the houses in search of mice, and many people are bitten in their own homes. Unfortunately, the majority of the people hold them in superstitious reverence and do not kill them for fear that they may be the reincarnation of their late grand-

Photo by Winchester

FIG. 26.18. The Egyptian Cobra. This deadly snake is shown with its hood spread ready to strike and inject its venom which may cause death in five minutes. Cleopatra is said to have committed suicide by pressing such a snake to her bosom.

mother or other relatives. This cobra may be six feet long, but it has the short erect fangs characteristic of the family and has to chew the fangs into the skin. Ordinary clothing would be a great protection from them, but the natives usually go around bare legged and bare footed.

The **king cobra** of Africa and parts of Asia stands supreme among the poisonous snakes of the world. It grows to a length of twelve feet and has venom able to cause death in a few minutes. When disturbed it does not show the nervous, threshing movements of many other snakes, but gracefully raises its head, spreads its hood, and may approach the intruder weaving from side to side ready to strike.

Africa is also noted for the **spitting cobra** that is able to spit its venom six or eight feet. It instinctively aims for the eyes and temporary blindness will result if even a small quantity of the poison reaches them.

Another member of the cobra family is the **asp,** which is well known because Cleopatra pressed an asp to her bosom to commit suicide.

In Central and South America the most dangerous poisonous snakes are the **bushmaster** and the **fer de lance,** both pit vipers with very bad reputations, which are well deserved.

While we are on the subject of foreign snakes we might mention those of the **boa family,** which are well known because of the great size of some of them. Fortunately, they are not venomous. They are constricting snakes, which have a habit of wrapping themselves around their prey
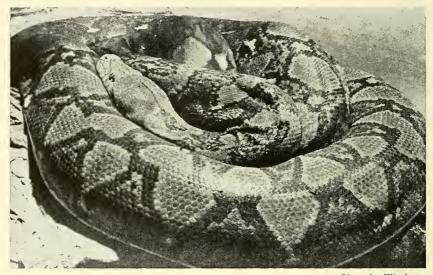
Photo by Winchester

Fig. 26.19. Regal python. This giant from the Malay Peninsula is about 22 feet long and weighs over 200 pounds. This species has the reputation of being the largest of the snakes.

and squeezing it to death before swallowing it. A snake swallowing its prey is a very interesting sight. They can swallow animals with a body diameter at least three times their own body diameter. A python can swallow a large sized pig or antelope. After squeezing it to death, it grasps one end of the animal with its jaws. The teeth point backward, so as the jaws are worked backward and forward the animal is gradually forced into the throat. Once through the throat the powerful peristaltic movements of the esophagus help pull the animal down. After finishing its meal, there will be a huge lump in the python's body, which will gradually diminish as the animal is digested.

Huge pythons have been known to eat naked native children, but show a distinct aversion to clothed persons and the tales of explorers

being squeezed to death by pythons or boa constrictors are probably just more of the many snake tales without foundation in fact.

The boa family includes many smaller snakes and the following giants.
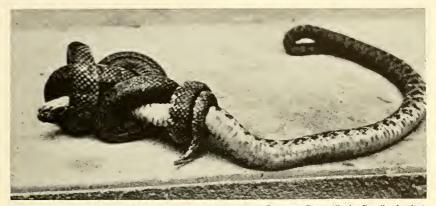
Regal python, of Indo-China, Burma, and the Malay Peninsula, which reaches the great length of thirty feet and a weight of 225 pounds.

African python, which grows as long as twenty feet.

Anaconda, or **water boa,** of South America, which also grows to twenty feet or a little more in length.

To get back to the snakes of the United States, we shall list some of the common nonpoisonous ones with some of their characteristics and habits.

Courtesy Ross Allen's Reptile Institute

FIG. 26.20. A king snake killing a rattler. Although the king is quite docile around people it becomes quite aggressive when it is near a rattlesnake. It grabs the rattler on the back of the head and squeezes it to death by constriction. The king is sometimes bitten in such fights, but is immune to the poison of the rattlesnake.

The most abundant of all the snakes in the United States are the striped snakes that have one or several longitudinal stripes running the length of the back. They are commonly called the **ribbon snakes** and the **garter snakes,** and may be found in the back yards of city dwellers as well as in the fields and forests. They eat cold-blooded animals, such as earthworms, frogs, and toads. Small ones are often carried by boys to frighten girls who "just can't stand the sight of wriggling snakes."

The **water snakes** live in and around water and eat fish, frogs, and toads. They are almost invariably called water moccasins by those who think that any snake around the water is a water moccasin. They are somewhat ill-tempered and able to give a painful bite, but carry no poison.
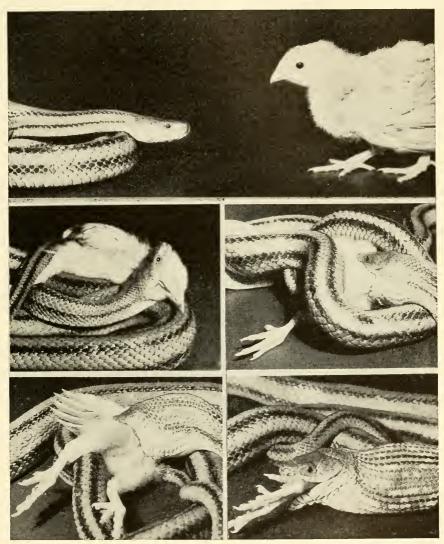
The **king snakes** are a highly beneficial group because of the large numbers of rodents that they destroy. They also eat other snakes and seem especially fond of poisonous ones. In Florida, tourists sometimes see fights between king snakes and rattlesnakes. Before the battle, the tourists place bets on one of the two and nearly always pick the vicious looking rattlesnake in preference to the slender docile king snake. However, when placed in the same pen together their dispositions change. The rattler seeks to escape, but the king grabs him, quickly coils about him, and squeezes him to death. Sometimes the king is bitten during the battle, but is immune to the poison and suffers no harm. The rattlesnake may then be eaten. The king snakes are very gentle toward man and make very nice pets that are entirely safe to handle, and they can hardly be recognized as the same pugnacious snake that attacks and destroys our most deadly reptiles without hesitation.

Probably the most interesting of our snakes is the **hognosed snake,** also called the spreading adder or blowing viper. If a person suddenly comes upon one it will rear up and spread the skin back of its head which makes it look like a hooded cobra. It blows itself up to more than twice its size and then forces air out of its mouth to produce a hissing noise. It feints as if about to strike. Because of this fierce behavior, most people think it is a deadly reptile; even its breath is supposed to be poisonous. However, this is all a bluff, for the hognosed snake will make no attempt to bite even if one slaps it in the face. When its bluff does not work, it may "play dead." It will roll over on its back, open its mouth widely, writhe around in the most realistic death agonies and then lie perfectly still. It can then be handled without showing any signs of life, but if placed on the ground with the right side up, it will give itself away by rolling over on its back. It seems to know instinctively that, in order to look dead, an animal should be on its back. The hognosed snake makes a nice pet and becomes very gentle after being handled a short time.

The **chicken snake** is a member of a group called rat snakes. These are all great destroyers of rodents. The chicken snake will come around barns and chicken houses in search of rodents and sometimes eat eggs and young chickens. They do more good than harm, but farmers, seeing only the poultry loss, usually dislike them very much.

The racers are a group of slender, nervous snakes that move quite rapidly. The **black snake** and the **blue racer** are common examples.

It would not be fair to conclude a discussion of snakes without mentioning snake superstitions. These are so numerous that it will be impossible to mention them all, but some of those that are widely told will be discussed.

FIG. 26.21. A chicken snake swallows a chicken. These photos show the extent to which a snake's mouth and throat may be distended to swallow its food. The victim is captured as the snake coils around it. The head is grasped in the snake's mouth and the body of the chicken is slowly worked down the throat by backward and forward movements of the lower jaw. The snake's small teeth point backward to aid in this process. This is a three-lined Florida chicken snake which is a valuable destroyer of rodents in spite of its occasional raids on the chicken yard.

"A coachwhip snake will wrap itself around a man and whip him to death." There is a **coachwhip snake;** it is one of the racers and the color of the long slender body and the arrangement of the scales make it look like a platted leather whip. If one were stepped on, it might thresh around and strike a person's legs with its tail, but that is as far as the truth of this superstition goes. They are entirely harmless, but are too nervous to tame easily.

"A hoop snake will puts its tail in its mouth and roll down a hill like a hoop in pursuit of a man. When it nears the man it straightens out and pierces him with a sting on the end of its tail that causes death." There is a hoop snake, or more commonly called the **indigo snake,** which grows to a length of nine feet and is our largest snake in the United States. It is a beautiful shining blue-black color and seems to greatly enjoy being handled by man. It is a favorite of the so-called "snake charmers" of the circus side shows, because it is so large and yet so gentle toward people. This snake never rolls like a hoop and no snake has anything like a sting in its tail.

"Some snakes will milk cows." Farmers sometimes accuse snakes of stealing the milk when a cow does not give as much milk as he thinks it should. No snakes are known that will take food in a liquid form and none have ever been observed milking a cow.

"Snakes can't bite under water." Snakes can and do bite under water; they do not strangle when they open their mouths under water. They prefer to escape, however, and if a snake knows you are coming, it will go the other direction. It is just as anxious to avoid contact with a person as a person is to avoid contact with it.

"Snakes are cold and slimy." Snakes are cold-blooded animals; which means that their body temperature is about the same as the temperature of their surroundings. They feel cold only if they have been on a cold surface. They are clean and dry unless they have just been in the water and are never slimy.

"If you are sleeping out on the plains put a grass rope around you, for if a rattlesnake starts to cross the rope, it will tickle his belly and he will turn back." Not true, they will readily cross any kind of rope.

"If a poisonous snake bites you kill a chicken and press the flesh against the bite. This will draw the poison out." Of all the snake superstitions, those concerning treatment of snake bite are the most vicious, for a person may rely on such tales and die as a result. This chicken superstition is absolutely false as are many others concerning the use of tobacco juice and whiskey.

The generally accepted first-aid treatment of snake bite is as follows. First, apply a moderately tight tourniquet about two inches above the

bite if the bite is on an area of the body where this can be done. This is called a lymph tourniquet since its purpose is to stop the movement of lymph and not blood. Then two incisions should be made through the fang marks and suction applied to remove as much lymph and body fluids as possible. Every fifteen minutes the tourniquet should be loosened and moved back up the limb an inch or two. As the skin puffs up

Photo by Winchester

FIG. 26.22. Snake Charmer? This young lady is attractive enough to charm almost anything, but this six-foot indigo snake would be just as gentle and easy to handle for anyone else. The indigo snakes easily become accustomed to being handled and actually seem to enjoy it. They are valuable as destroyers of rodents.

farther from the bite, additional cuts should be made and more suction cups applied. The victim should be kept as quiet as possible so that his muscular movements will not push the lymph on into the blood system, since most of the poison in the tissues is picked up by the lymph system. In the absence of snake kits containing suction cups, it is generally considered safe to suck the poison out with the mouth. Even though some of it should be swallowed, the pit viper venom is destroyed by the digestive juices. A small amount of the poison might be absorbed, however, if there are cuts or sores on the mouth. As soon

as possible antivenin should be injected. This could formerly be done only after reaching a hospital or doctor's office. Today there is a snake kit which contains a powdered form which consists of a mixture of the antivenins for the chief kinds of pit vipers in the United States. This powder can be dissolved in distilled water and injected immediately in the field. Unlike the liquid preparations, this powder does not need to be refrigerated. Even though the patient appears to be getting along very well he should be taken to a physician as soon as possible. Blood transfusions may be necessary because of the destruction of the blood by the poison.

"Snake charmers can charm snakes." There is a common belief that some persons have some special gift by means of which they can charm snakes and handle dangerous specimens without danger to themselves. In some cases they use music supposedly to effect the charm. There can be no charming of snakes, although it is possible for persons to study the habits of snakes and do things with them that seem very dangerous to a person who thinks of all snakes as vicious aggressive creatures. The snake charmer of the circus side show usually handles only harmless snakes that any person in the audience could handle just as safely.

"If you pull a snake's fangs out it will be harmless." This is another one of those vicious superstitions, for a person can lose his life if he depends on its veracity. The snakes with the long curved fangs have a succession of them under the mucous membranes ready to descend into place if one of the functional fangs is lost. Sometimes their fangs break off in nature, but they are replaced within a few days.

Classification and Derivation of Scientific Words

Phylum Chordata (Cont.)
> Class D. Amphibia (Gr. *amphi,* double; *bios,* life; lead a double life, are both water and land animals).
>> Order 1. Apoda (Gr. *a,* without; *pous,* foot; have no feet). Tropical, burrowing, worm-like amphibians.
>> Order 2. Caudata (L. *cauda,* tail; tailed amphibians). Newts and salamanders.
>> Order 3. Salientia (L. *salio,* leap; leaping amphibians). Frogs and toads.
> Class E. Reptilia (L. *reptilis,* creeping).
>> Order 1. Testudinata (L. *testudo,* turtle). Turtles and tortoises.
>> Order 2. Crocodilia (L. *crocodilus,* crocodile). Crocodiles and alligators.
>> Order 3. Squamata (L. *squama,* scale). Lizards and snakes.

REVIEW QUESTIONS

1. Describe changes that take place in larval amphibians that adapt them for life on the land.
2. How may frog and toad eggs be distinguished from one another?
3. Name the important parts of the reptile egg that enable it to develop on the land.
4. Tell how climate might have played a part in the decline of the reptiles and the rise of the mammals.
5. What body structures form the "shell" of the turtle?
6. Why is the glass snake thought of as a snake when it is a lizard?
7. Name the easily recognized characteristics of the pit viper head.
8. How is the rattle of the rattlesnake formed?
9. Compare the fangs of the cobra family with the pit viper family.
10. List some of the snake superstitions that you have heard.
11. How can the Colorado axolotl be made to undergo metamorphosis?
12. Compare fertilization in the frog and the salamander.
13. How could the mud eel have lost its hind legs in the process of natural selection?
14. How far can a snake strike?
15. Compare the poison of the pit vipers with that of the coral snake.
16. Tell how the Gila monster injects its poison.
17. Describe the proper method of first-aid treatment for snake bite.

27

The Birds

Class Aves

Birds are an important and highly beneficial class of vertebrates so far as man is concerned. No music is more sweet than that of our song-birds singing in the trees. Their beautiful coloration has an esthetic appeal unequaled among living things; they show many brilliant hues, but never do you see a lack of harmony as may sometimes be found in man-made combinations. Some of them have been domesticated and contentedly lay egg after egg for human consumption. Their bodies make delicious eating; the mere mention of southern fried chicken is enough to make nearly anyone's mouth water. Game birds challenge many sportsmen, who get recreation in hunting. Birds feed on many harmful insects and eat seeds of harmful weeds; it is doubtful if man could grow crops at all if the birds did not give this valuable assistance.

Wherever birds congregate in large numbers there may be built up a great deposit of feces from their bodies which is collected and sold commercially as guano, one of the richest natural fertilizers known. There are islands off the coast of Peru, frequented by water birds, where deposits more than one hundred feet deep have been found. They deposit 750 tons per acre per year.

Some of our birds help to get rid of dead animals by acting as scavengers. These are the vultures or buzzards that glide high in the air scanning the ground for signs of a dead animal on which they may feast. No animal body seems repulsive to them even though it is in an advanced state of decomposition.

We could not conclude a listing of beneficial attributes of the birds without mentioning the use of their feathers as costume decorations. A generation or so ago, ladies' feather-trimmed hats were the rage. Fortunately, the styles changed, or many beautiful birds might have become extinct, for many were killed for their feathers. Ostrich plumes are still used extensively, but these are painlessly clipped from domesticated birds, so there is no harm done.

Of course, all the birds are not beneficial. There are some that eat quite a bit of grain or tender shoots of growing plants and thus do harm.

Some hawks catch chickens, although the great majority are beneficial because they destroy harmful rodents, and we should kill only those known to be harmful. Some birds, like the English sparrows, live a little too intimately associated with man and may be a general nuisance and cause quite a mess around the place.

As a whole, however, we must consider the birds great friends of man and give them protection. Excessive clearing of the land will remove the trees and protected places on the ground where birds may build their nests and, thereby, reduce their numbers. Reforestation and protection of existing forests conserve our birds as well as our timber. Game laws are set up to help protect our game birds and should be rigidly respected.
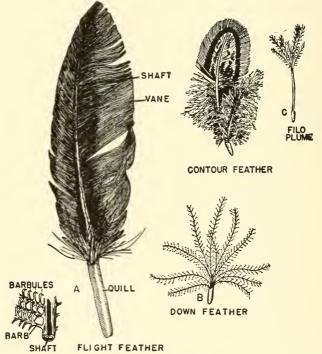
Characteristics of Birds

Feathers are the most distinguishing feature of birds; all birds have feathers and no animals except birds have feathers. There are three kinds. Those seen from the outside are the large **contour feathers,** which consist of a central shaft with parallel barbs to the sides. These give shape to a bird's body and those on the wing are spread to offer resistance to the air, while those on the tail form a rudder by means of which the bird controls the direction of its flight. The **down feathers** consist of a central shaft with the barbs coming out irregularly so as to form a soft fluffy tangle. They are found under the contour feathers and help hold the warmth of the body. There is no material known that is more efficient for holding heat than down. We take advantage of this by making quilts of down, which may be very light yet cozy and warm on the coldest nights. The down feathers are very abundant in the ventral posterior region of the body and are not covered with contour feathers in this region because this part of the body covers the eggs and keeps them warm when a bird is sitting on a nest. Some duck hunters say that it is best to let a duck fly over you and shoot him from the rear, for the bullets can penetrate this soft downy region much better than the tough contour feathers at the front of the body. Some feathers may be a mixture of the two, downy near the body and contour in type on the outside, and, thus, serve a dual function. The filoplumes are little hair-like projections from the skin that seem to have no particular purpose, but make it harder to pick a chicken.

Birds are **warm-blooded** animals. These are the first of the animal groups studied that have this characteristic. Those up to this point are called **cold-blooded.** This term is confusing because it does not mean that they have cold blood necessarily. It simply means that the temperature of the body, including the blood, varies according to the sur-

rounding temperature; if the air is cold the blood will be cold, if the air is warm the blood will be warm.

Warm-blooded animals, on the other hand, have a constant high body temperature, and the blood and the rest of the body remain at about the same temperature regardless of the surroundings. If the air is cool, extra heat will be generated through metabolism to keep the body warm. Birds will have a normal body temperature of about 105 degrees, which

FIG. 27.1. Types of feathers.

is nearly always above that of their surroundings, so much of their food is burned for heat rather than energy. Since the reptiles, as an example of cold-blooded animals, burn their food primarily for energy, the birds must eat much more than reptiles. An average snake will not eat oftener than once a week, but birds seem always to be hungry; chickens seem to be scratching and pecking around constantly in search of food.

Birds have **streamlined bodies.** They are flying animals as a group, and we find nearly every part of the body modified in some way to accommodate flying. Their streamlined bodies offer a minimum of re-

sistance to the wind and they are capable of sustained high speeds. Many of the principles of airplane construction have been patterned after the bodies of birds.

Birds have a **keel-shaped sternum** or breastbone, which accommodates the large amount of muscle necessary for flight. The space on either side of the keel is filled with large muscles which are used on the down beat of the wings where most of the power is needed. The muscles which lift the wings upward are also on the underside of the wings, but these muscles, by means of a long tendon which circles over the shoulder, are able to raise the wings. As a result of this unusual arrangement there is little flesh on the back of a bird. Flightless birds, such as the ostrich and emu, have vestigial wings and have lost the keel on the sternum.

The birds have a **highly developed cerebellum,** which is the part of the brain that regulates the many unconscious movements associated with equilibrium and muscle coordination. This is another important adjustment to flying. Consider a bird flying toward a cliff at high speed. It will seem as if he surely is going to dash himself to pieces against it, but suddenly he throws his wings in reverse, spreads his tail, comes to a dead stop, and settles on a slight projection. All this involves a high degree of coordination of the various muscles of the body, made possible by the highly developed cerebellum.

Birds have **air sacs** that run from their lungs out into the flight muscles and also extend into many of their bones. The airfilled bones are very light, and this helps the birds by reducing the weight which they must lift when flying. Also, the air sacs in the muscles function in respiration while a bird is flying. When not flying, birds expand their chest for inhalation; but while flying, the chest bones must be held rigid as a support for the chest muscles. The alternate contraction and relaxation of these muscles, however, exert a bellows-like action on the air sacs between them and air is pumped in and out of the lungs with each beat of the wings. In our less efficient lungs at least one third of the air, called residual air, remains in the lungs and air passages even with a maximum exhalation. When we inhale, the pure air coming in mixes with the foul air already in the lungs. As a result, the bird's lungs are far more efficient than human lungs. It has been estimated that man would need lungs ten times the present size to supply the oxygen needed to enable him to fly under his own power.

Birds have a **syrinx** which is located at the point where the trachea divides to form the bronchi in the chest. This structure is found only in birds and is not homologous with the voice mechanism in the larynx of other vertebrates. The bird produces its sound by means of vibrat-

ing membranes located on the sides of the syrinx. Air sacs from the
lungs press against these membranes from the outside. As the current
of air rushes through the syrinx, it pushes these membranes outward,
but they are pushed back by the pressure generated in the air sacs and
this sets the membranes into vibration. By changing the shape and ten-
sion of the membranes, the pitch can be changed.

Birds have a **perching adaptation** in the tendons of the legs. If you
were to try to sleep perched on the limb of a tree waving in the breeze
you would not be likely to stay on the limb for long. The birds are able
to do this because the tendons of the leg which are attached to the claws
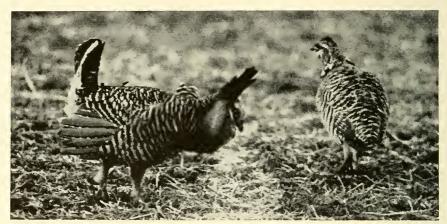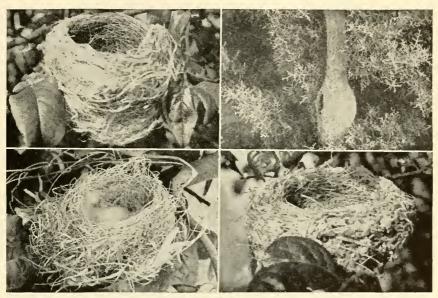
FIG. 27.2. Male prairie chicken booming before female. These birds have a rather
elaborate courtship that may continue for as long as six weeks before mating.

are pulled when the legs are bent and the claws automatically close.
Thus, the weight of the bird's body on the bent legs keeps the claws
tightly gripped on the limb.

Bird Reproduction

There seem to be two primary objectives in the life of the majority
of animals; first, the getting of food, and second, reproduction. When
you have learned how animals accomplish these two vital functions, in
all their ramifications, you have an explanation for most of their habits.
Food getting in birds is so varied that it cannot be discussed for the
group as a whole, although some habits of feeding are discussed later in
the chapter. However, reproduction follows a similar pattern in all
birds and will be studied for the group.

Mating habits among birds are quite interesting. Some, such as the prairie chickens, have an elaborate courtship in which the males strut and display themselves, stamp their feet, and give out loud booming calls to attract the females to them. They may keep this up for six weeks before the females condescend to notice them. Many birds remain together after copulation and share in the building of the nest, the incubation of the eggs, and the care of the young. Some choose mates and remain together for life.

Fig. 27.3. Bird nests. A remarkable illustration of the power of instinct is brought out in the building of bird nests. Each species of bird gathers similar materials and constructs the nest in a size and shape that is characteristic of the species. These nests are: upper left, yellow warbler; upper right, bottlebird; lower left, orchard oriole; and lower right, Arkansas goldfinch.

The building of the nest illustrates one of the most remarkable instincts in the entire animal kingdom. Each species of bird has its own type of nest. Now, consider a young female preparing to lay her eggs for the first time. She has never seen a nest built; she saw one after it was built, but she was quite young at the time. Yet, she is able to select the proper materials and put them together in the manner characteristic of the species. It may be made of sticks, twigs, or grass; it may be shaped as a simple cup, or it may be completely inclosed to form a house; it may be built on the ground, in a tree, or against a sheer cliff; yet she selects the proper materials, builds it the proper way, and in the proper

place. The eider down duck lines her nest with the fluffy down feathers plucked from her own body, which we remove to stuff our best down quilts. There is a bird, the Selangane swift, that lives in Malay and surrounding Pacific islands that lines its nest with a gelatinous material secreted from its throat. These nests are collected and sold to the Chinese to make bird's nest soup. The nests are built in rather inaccessible

Photo by Winchester

FIG. 27.4. Young barn owl. Most young birds are quite unattractive when young as illustrated by this specimen. This is in contrast to many higher forms of animal life where the young are more attractive than the adults.

caves along the seacoast, and their collection is somewhat hazardous. The best grade nests bring from ten to fifteen dollars per pound.

The number of eggs laid by birds varies from one to twenty or more. The eggs are similar in structure to the reptile eggs, although the shell is calcified and brittle. Also, they must be incubated, for the birds are warm-blooded animals and a tiny embryo cannot generate enough heat through metabolism to keep its body temperature normal. We sometimes have to place human babies in incubators when they are born prematurely and are not large enough and well-developed enough to produce the heat needed to maintain normal body temperature. The female

usually does the incubating, but the male often takes turns to give the female some time off the nest. In other birds, he lets her do all the incubating, but brings her food during the one to four weeks required to hatch the eggs. The birds turn the eggs with their bills regularly, for an embryo cannot develop if left in one position too long.

Most of them emerge as ugly, naked, blind bundles of protoplasm whose only body reaction seems to be to open their mouths at the slightest sound and awkwardly stretch their necks for a morsel of food. In

Photo by Chas. W. Schwartz

Fig. 27.5. A red-winged blackbird female feeding young that has just left the nest. The maternal instinct is strongly developed in birds and they care for their young with great solicitude.

spite of such an appearance, the parents seem extremely proud of their offspring and show a solicitude for them that is unexcelled in the animal kingdom. The female shows an aggressiveness and resourcefulness in protecting them that is in direct contrast to her usual meek, submissive manner. A mother hen protecting her baby chicks can make a dog turn tail and run. One of the cleverest means of deception known is used by the female quail to protect her nest. The nest is on the ground and it would seem a simple matter for animals to find it and devour the eggs. However, when the mother quail hears a large animal approaching, she will suddenly run from the nest fluttering and falling about like a bird

with a broken wing. The predator will probably give chase, thinking that this will be an easily obtained meal. However, after leading him quite some distance away from the nest, the quail will majestically rise in the air, with the characteristic whirring of her wings, leaving the puzzled predator behind, a safe distance from the nest.

After the eggs have hatched, the mother, and sometimes the father bird, spend most of their time searching for food to try to satisfy the ravenous appetites of their offspring. They cram the food down the throats of their babies, for most young birds are not able to swallow properly. Many of the sea birds swallow fish and latter regurgitate the partially digested fish to feed their young. Pigeons secrete a nourishing liquid from their crop, which is called pigeon milk, that is used to feed their squabs.

Many game birds, including quail, pheasants, grouse, and chickens, have offspring which have their eyes open and their bodies covered with down feathers when they hatch. These are known as **precocious young.** They are able to run about and pick up their food from the time they are hatched, and their parents do not put food into their mouths. The birds which are hatched as blind, naked, completely dependent offspring are known as **altricial young.** For the first seven or eight days a nestling robin, as an example, is nearly naked, and experiments show that its temperature will drop quickly if not kept brooded by a parent. Thus, it is actually cold-blooded like the reptilian ancestors. Young birds, such as the hummingbird, exercise their wings on the edge of the nest until they are able to fly successfully the first time they leave the nest. Thrashers, mockingbirds, catbirds, and many others of our common dooryard birds, usually jump from their nest two or three days before they can fly. During this period of time they must hide in the weeds and bushes where their piercing hunger calls lead their parents to them with food. It is during this unprotected period that house cats and other predators take a tremendous toll of young birds. After they can fly, the fledglings will follow their parents from tree to tree for about ten days or longer. With wings fluttering and mouths open widely, they noisily beg for food.

Soon, however, the mother birds starts to build another nest for her second brood. She now appears to lose interest in her first brood and not only stops feeding them, but often chases them from the neighborhood. They now must fend for themselves. She has devoted her full time to their care for a period of about six weeks and now must give her time to a new nest and brood.
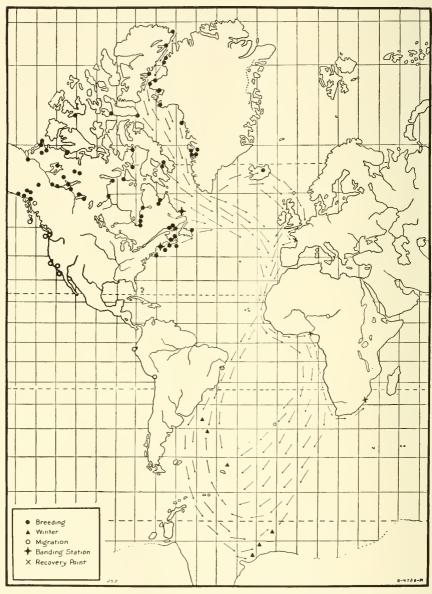
Migration

Some of the birds are permanent residents. They stick it out through the winter months just as most of us have to do, but a great number of birds spend the summer in northern regions and migrate to southern regions where the temperature will be mild during the winter months. If you get a good pair of binoculars and focus on a full moon during a clear night of the migrating season, you may be rewarded by seeing black shapes by the hundreds pass between you and the moon. These will be birds, perhaps of a number of different species, flying about a mile high in their semi-annual migration.

Most birds stop along the way and do not cover more than about twenty-five miles a day. Each species has its own time of migration and its own route. Governed by the length of day or some other seasonal factor, the time of arrival is fairly regular each year. The arrival of the swallows at the mission San Juan Capistrano in California occurs on almost exactly the same day each year.

A number of birds winter in South American and spend the summer in northern Canada, traveling up to 14,000 miles per year. The long-distance record, however, is held by the Arctic tern, which nests in the summer far into the Arctic Circle, then flies down the eastern coast of Canada, across the Atlantic, down the west coast of Europe, down the west coast of Africa, and finally ends up in the Antarctic regions to spend the winter. This makes a yearly round trip of about 25,000 miles, which is quite a distance even in these days of modern transportation. They must like the sunlight, for they are near the poles at the season when the sun never sets.

There has been considerable speculation about how birds find their way in their migration flights so that they take the same routes and arrive at the same places each year. Those who have a hobby of banding migratory birds report that they tend to return to the same yards each year. In some cases it appears that an older bird leads the way on migration flights, and he goes by landmarks along the way. Landmarks are without doubt a very important factor in many bird flights, but this method could not be used for all migratory flights. There are some migrations which cover thousands of miles of open water and end on a small island. Birds hit this point each year with an accuracy which is equal to the best we can do with all our complicated instruments. Some have suggested that birds might have some sense organ which tells them their position by the magnetic field of the earth and the force brought about by the earth's rotation. This is still one of the questions of science which must be investigated further before we have a complete answer.

Fig. 27.6. The route of migration of the Arctic tern. This bird holds the world's record for distance traveled in migration making a yearly round trip of about 25,000 miles.

We do know, however, that the urge to migrate develops as a result of the changing length of day that comes with the seasons. Suppose we take a migratory bird in the north in midsummer and put him in a cage where he receives light for only a part of each day. This artificial short day causes the development of the urge to migrate, and when he is released from the cage he will start his flight south. Most birds feed only when it is light and roost at night. Many come north for the summer, because the days are longer in the north during the summer than they are in the south. In winter, however, the reverse is true—the longer days are to be found in the south. Long days are also correlated with abundant plant growth, and the birds find abundant food the year around when they migrate to the regions with the longer days. Poultrymen sometimes take advantage of the habit birds have of eating as long as it is light and keep a light on in their poultry houses. This causes the chicken to feed almost continuously and they grow much faster and lay more eggs than is possible when they spend about one half of their time roosting.

Typical Birds

There are about twenty-five orders of birds with many varied families under most of the orders, so it will be impossible to give a complete survey of the field. However, by taking a few well-known birds and learning something about their habits, we may better understand the class.

The Eagles. Perhaps it is appropriate that we start our study with the group that includes the American national bird, the bald eagle. This eagle is not really bald, but has a thatch of white feathers on its head that makes it appear bald at a distance. It is a majestic bird, with a wing spread of about six feet, that soars high in the air, only to drop like a bullet when it spots its prey. It catches fish and some mammals for food. Unfortunately, everything that can be said about our national bird is not good. It is sometimes a robber. It will soar in the air watching the osprey hawks. When the osprey dives in the water and brings out a nice wriggling fish, the eagle will drop out of the sky and attack the smaller osprey, causing it to drop the fish. The eagle then drops down, catches the fish, and flies away. There are tales of eagles carrying off small children and other large objects, but even the largest of the eagles could not lift a weight of more than eight pounds. Eagles build huge nests of sticks in rocky, inaccessible places in which they live and raise their young year after year.

The Owls. "Wise as an owl" is an old saying; it would seem that any creature that looks so dignified and sits so long, apparently in deep

meditation, must be wise. However, when night comes the owls no longer sit, but become quite active as they fly about in search of nocturnal rodents. They have eyes that are probably the keenest in the animal kingdom. During the daytime the pupils become reduced to small dots, but, contrary to superstition, they can see during the daytime. At night, in the reduced light, the pupils enlarge tremendously, enabling

Courtesy Chicago Natural History Museum

Fig. 27.7. The bald eagle, our national bird, is a symbol of freedom as it soars unrestrained high in the air.

them to see clearly in the darkest forests. The pupils are able to change their size almost instantly to accommodate for changing light intensity, so that an owl can chase a mouse from the bright moonlight into a dark forest without difficulty. This can easily be demonstrated; if a flashlight is passed back and forth in front of an owl's eyes the pupils contract and dilate as rapidly as the light passes across in front of them. We can realize how superior this is to our own pupil accommodation when we remember how we stumble around and sometimes sit in someone's lap

in a theater, after coming in from bright daylight. The eyes of owls are placed side by side on the front of the head so that they look straight ahead, and the owls have to turn the head to see in different directions. When an owl looks at something behind it, the head gives the appearance of being attached backwards.

Most owls are beneficial since rodents seem to be their favorite food, but sometimes the great horned owl finds that it is easier to catch chickens and other domesticated birds, even including turkeys. The monkey-faced or barn owl is highly beneficial and should not be destroyed. The
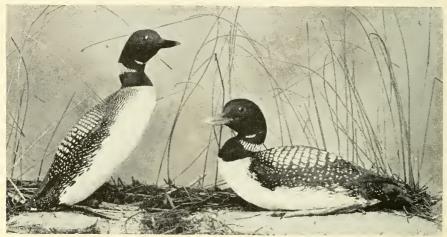
Photo by Winchester

Fig. 27.8. A barn owl spreads it wings and prepares to repel those that intrude on its privacy during the daytime when it should be sleeping. At night it catches many harmful rodents.

little screech owl gives out an eerie cry that may be frightening on a dark night, but it eats many insects and mice. In many of the western states there is a superstition that the little burrowing owl lives in the same burrow with prairie dogs and rattlesnakes. It often lives in a prairie dog hole, but devours the original occupant first and in turn is probably devoured by any rattlesnake that may enter the hole.

The Vultures. The vultures, or buzzards, are close relatives of the hawks, but lack the strong beak and the strong legs of the hawks. Therefore, they do not attempt to catch live prey, but devour anything that is dead. No rural landscape is complete without several buzzards gliding high in the air on a sharp lookout for the carcass of a dead ani-

mal. Upon sighting anything that looks promising they circle around and slowly approach the earth. Other buzzards in the distance see this characteristic reaction and come to join the feast. The body of a dead cow will be picked clean leaving only the bones before the buzzards have finished. The repugnant odor of decaying flesh seems not to bother them at all. They seem completely immune to the poisons of bacteria that may be present in such flesh, although other animals may be killed by it. Since they cannot carry things well in their claws, the young are fed on a regurgitation of partly digested flesh.

Courtesy Chicago Natural History Museum

FIG. 27.9. A pair of loons. These birds are common around our northern lakes. They are champion diving and swimming birds; they can swim under water faster than most fish.

The Loons. Visitors to the lakes in the northern part of the United States will probably never forget the cry of the loon sounding over the water in the middle of the night like the hysterical laughter of a lunatic. However, the loon is anything but a lunatic. It is very hard to get near one; it will dive under the water when you approach in a boat, suddenly pop up behind you, dive again, and appear again in some unexpected direction as if mocking your pitiful efforts to outsmart it. Loons are the champion diving birds, sometimes diving and swimming under water to a depth of fifty feet. A fish or frog does not have a chance against a loon, for the loon can outswim it under water.

The Hummingbirds. These are the midgets of the birds; the eggs are little larger than pearls, and a young hummingbird will fill only a portion of a teaspoon. Their wings are small and vibrate at such a high rate of speed that the characteristic humming sound is produced

that gives them their name. One of their most interesting achievements is their ability to remain motionless in mid-air. When doing this the wings vibrate so rapidly that they cannot be seen, and it appears as if a wingless bird is suspended in space without any visible means of support. Since even their tiny bodies would be too heavy for most flowers, this is an adaptation for their nectar-sucking habits. They suspend themselves in the air while thrusting their long bills down in the flower for a drop of

Photo by R. Marlin Perkins

Fig. 27.10. Ruby-throated hummingbird. Although the hummingbird is the smallest of our birds it is almost fearless, seeming to have confidence in its speed and maneuverability as a means of escape from enemies.

sweet nectar. A jar of sugar-sweetened water outside a window sill may attract these friendly little visitors for close observation. Small as they are, they are among the most fearless of birds, evidently feeling confidence in their speed and maneuverability to escape at a sign of danger.

The Ostrich. While we are dealing with extremes we might mention the largest of the living birds. The ostrich may be more than eight feet tall and weigh up to 300 pounds. It uses only two toes which are covered with broad pads and are well adapted to travel in the desert.

Ostriches easily take twenty-five feet in a stride and travel more than twenty-five miles an hour. The tale about burying the head in the sand to escape detection seems to have no foundation in fact. They lay a single egg which will weigh about three pounds and requires forty-five days' incubation for hatching.

Photo by Winchester

Fig. 27.11. The ostrich. One of the large flightless birds that depends on its running speed rather than flight to escape its enemies. When cornered it can deliver a powerful kick with its strong legs.

The Woodpeckers. It would be hard to believe that any bird had a bill sharp enough and a head and neck strong enough to dig holes in solid wood if we did not actually see it. The woodpeckers are very well adapted to this activity. The feet have sharp claws that can cling to slight outgrowths of bark and the tail is held against the tree for firm support, while the long sharp bill is driven into the wood with a very rapid series of blows, similar to an air hammer digging into concrete. Most woodpeckers are beneficial because their pecking is done in search of insects that are boring through the wood. The tongue, well adapted for getting the insects, is long and bears a barb on the tip, so that it can

be thrust down a slender hole to stick insects and bring them out to eat. One of the woodpeckers, the yellow-bellied sapsucker, has become harmful, for it has discovered that it can dig holes in trees and sap will fill the holes. Then it can suck this sap out as its food.

FIG. 27.12. A red-headed woodpecker at the entrance to its nest. Note how the tail is used as a brace to give the bird more power for its pecking.

The Cowbird. Cowbirds are one of the few birds that are parasitic. They lay their eggs in other birds' nests and allow foster parents to feed and care for their young offspring. The female cowbird spends most of her time during the nesting season searching for recently built nests in which the clutch of eggs is not complete and the parents have not yet started incubating. When she finds such a nest she picks up one of the eggs in her bill and flies away with it. Early the next morning, usually before sunrise, she slips into the nest and replaces the missing egg with one of her own. When the rightful owner of the nest comes to lay another egg, she finds the number of eggs unchanged and usually does not notice that one of the eggs is different in size and color. There is an interesting hypothesis to explain this odd practice of the cowbird. The old name for this bird was buffalo-bird, because it always fed around the great herds of American buffaloes that once inhabited our great plains. Since these buffaloes were great wanders, the cowbirds often found themselves far from their own nest when the time came to lay an

egg. They had to deposit it somewhere and those that were fortunate enough to find a fresh nest of another species left survivors, whereas those that left their egg on the ground did not. In this way, according to this hypothesis, the instinct to lay their eggs in the nest of other birds was developed in the cowbirds by natural selection.

A few birds reject the strange egg. The yellow warbler buries it in the bottom of her nest often with several eggs of her own. She then builds a second nest over the first one and lays a new clutch of eggs. The robin, which has a blue egg very different in color from the pale spotted egg of the cowbird, throws the foreign egg from the nest.
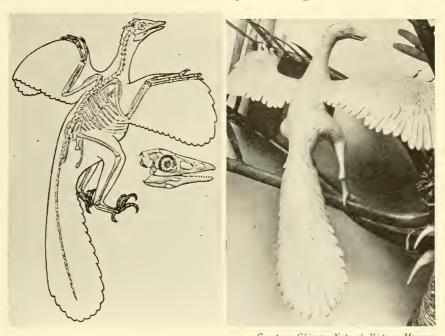
Photo by Winchester

FIG. 27.13. The stork. Although not found in the United States the stork is one of the best known birds because of its traditional baby carrying activities. This habitat group in the Chicago Natural History Museum includes a typical nest and scene as found in the coastal regions of Eastern Europe.

Most other birds, however, seem not to notice the difference. A commonly parasitized species is the song sparrow which lays a spotted egg rather similar in appearance to that of a cowbird, although smaller. The incubation time of the cowbird is only eleven days, one day shorter than that of the song sparrow. This generally results in the young cowbird hatching one day before the sparrows. When food is brought to the nestlings, the larger cowbird manages to get most of it and may even crowd the young song sparrows from the nest. It is an amusing, yet somewhat tragic, sight to see a song sparrow stuffing food down the huge mouth of a baby cowbird twice her own size while her own offspring are begging for food. As soon as the cowbird is able to feed itself, it deserts its foster parents and joins a flock of birds of its own

species. It is doubtful that the cowbirds reduce the song birds to any appreciable extent, however.

Quail. The quail, partridge, or bobwhite, so called by different people in different sections of the country, is among the most tasty of the game birds. It has comparatively small wings and must vibrate them very rapidly during flight, so that they produce a characteristic whirring noise that sounds like a miniature airplane taking off.

Courtesy Chicago Natural History Museum

Fig. 27.14. Left, skeleton of Archaeornis, an extinct ancestor of modern birds. Right, Restoration of Archaeornis. Note that this ancient bird had teeth, a long bony tail, and lacked the well developed breast muscles of modern birds. It also had digits and claws on its wings.

The male excavates a place in the ground and lines it with leaves and grass and takes turns sitting on the eggs. The young quail usually stay with their parents after they have matured, so quail are usually seen in coveys. When flushed they scatter in all directions and reassemble after the danger is past, finding each other through a special call. When sleeping, the covey is gathered in a circle facing outward, so that if they are disturbed during the night they can take sudden flight without colliding with others in the darkness. In the spring the coveys separate and the males take up a stand and give their bobwhite call hoping to

attract a female to their nesting grounds. Bachelor males will keep up the call throughout the summer.

The Storks. Strange to say, one of the best-known birds does not even live in the United States, although a close relative, the wood ibis, is found along our shores. The storks are abundant in the coastal regions of Europe and have a habit of building their nests on the tops of houses. In many countries this is considered an omen of good luck and they are never driven away. Just how they became an accessory in ma-

FIG. 27.15. Emperor Penguins from the Antarctic. These unusual birds live in a land of perpetual ice and snow. The female lays a single egg and incubates it during the antarctic winter when the temperature averages 50 degrees below zero. These specimens were collected by Admiral Richard Byrd and now form a habitat group in the Chicago Natural History Museum.

ternity is not clearly known, but a stork serenely perched on one leg on top of a chimney after a baby was born would offer an easy answer to embarrassing questions from the other children. The storks are members of the wading birds whose long legs make it possible for them to wade in shallow water picking out fish and other water animals with their long bills.

Archaeornis. This is a prehistoric bird whose characteristics give us an insight into the origin of birds. Delicately preserved remains of this bird have been found in Jurassic deposits near Solenhofen, Germany.

These fossils show that the birds and reptiles are rather closely related, for Archaeornis has many reptile-like characteristics, such as teeth and a long bony tail, but since it also had feathers there is no question but that it should be considered a bird. This bird had little, if any, power of flight, for the wings were not well developed and it did not have the enlarged breastbone to accommodate the large breast muscles necessary for effective flying. It also had three claws on the anterior portion of the wings representing the termination of three of the five digits. Thus, the bones of the front leg had not yet become thoroughly adapted to support wings. These and other characteristics give us a good idea as to the line of development through which ancestral birds have passed.

Classification and Derivation of Scientific Words

Phylum Chordata (Cont.)

Class Aves (L. *avis,* bird).

REVIEW QUESTIONS

1. Discuss the economic importance of birds.
2. Name the types of feathers found on birds and give the function of each type.
3. What is meant by the term "warm-blooded" as contrasted with "cold-blooded"?
4. What is the significance of the highly developed cerebellum in the birds?
5. What special adaptation do birds have that enables them to remain perched on a limb even when asleep?
6. Discuss nest building, egg incubation, and protection of the young in the birds.
7. Discuss bird migration.
8. Tell how an eagle takes a fish away from an osprey hawk.
9. How are the eyes of owls adapted for night flying?
10. How do hummingbirds suck nectar from flowers?
11. How does the cowbird get foster parents to raise its offspring?
12. Distinguish between precocious and altricial birds.
13. When are most young birds in greatest danger from predators?
14. Why are owls of great value to man?
15. How are vultures beneficial?
16. Tell how a bird breathes in flight.
17. How do quail protect their nest from enemies?
18. What is the syrinx, where is it found, and how does it function?

28

The Mammals

Class Mammalia

The mammals include the largest and most intelligent of the animals on the earth. They are a very successful group, having replaced ·the reptiles as the dominant large animals of the earth. Many body organs, such as the heart and brain, reach their height of development in the mammals, culminating a long series of gradual changes that started back in the invertebrates.

Characteristics of the Mammals

Hair. Only the mammals have hair on their bodies; most of them have the body almost covered with hair. Even man, whom we think of as a fairly hairless creature, has hair everywhere on the body except the palms of the hands and the soles of the feet.

Mammary Glands. The mammals take their name from the mammary glands which, in the females, enlarge and produce milk when they bear young. We commonly express this by saying that the mammals nurse their young. Embryonic mammals have a mammary ridge on either side of the ventral surface of the body. In most mammals nipples develop along the entire length of this ridge; dogs and cats are typical examples. In some mammals, such as horses and cows, nipples develop only at the posterior end of this ridge; in others, such as elephants and human beings, only a single pair of nipples may develop at the anterior end. Occasionally, however, supernumerary nipples appear in addition to those which are usually found in the species. Cows may often be seen with an extra pair of nipples anterior to the two normal pairs. These are usually rudimentary and give no milk. Human beings sometimes have from one to three pairs of nipples posterior to the normal pair, formed in a row similar to those found in the dog.

Diaphragm. This is an internal muscular partition separating the chest from the abdomen which can be raised and lowered to exhale and

inhale air. Mammals also use chest expansion for respiration, as is done in the reptiles and birds.

Warmblooded. Like the birds, the mammals maintain a constant high body temperature. The rate of metabolism is rather high, and this generates the necessary heat which holds the body temperature at an even, high level when outside temperature fluctuates.

Complex Teeth. The teeth in those lower vertebrates possessing them are usually just a row of cone-like projections, with a few exceptions, such as the fangs of poisonous snakes. In mammals, the teeth are
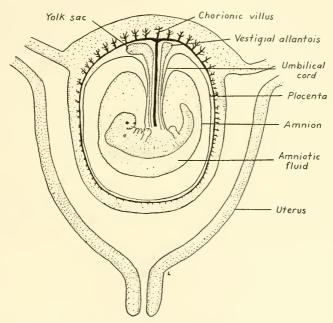
FIG. 28.1. Developing embryo of a mammal. Note that the yolk sac is much smaller than in a reptile or bird and the allantois is vestigial and forms a part of the umbilical cord.

specialized to accomplish specific functions. There are **incisors** for cutting; **canine,** for tearing; **pre-molars** and **molars** for grinding. These are developed in varying degrees in different mammals according to different feeding habits.

Placenta. All but the two most primitive orders of mammals have a placenta, which is an organ that grows out from a developing embryo and becomes firmly attached to the uterus of its mother and absorbs food and oxygen from the blood of the mother. When the mother nourishes the embryo in this way it is unnecessary to have a large amount of yolk

in the eggs, so mammal eggs are much smaller than those of other vertebrates. A rabbit egg is no larger than a dot made with the point of a fine-pointed pencil. This is **true viviparous** reproduction, with the young being born alive, in contrast to the **oviparous** reproduction found in most other animals where eggs are laid. There are some egg-laying animals whose eggs hatch before being laid, so that the young are born alive. This is sometimes called **ovoviviparous** to distinguish it from the true viviparous method where the embryo receives nourishment from the mother's blood during development.

Highly Developed Cerebrum. Whereas the birds concentrated on a highly developed cerebellum, for control of equilibrium and muscle coordination necessary for flight, the mammals have developed the cerebrum to the greatest size and complexity found in the vertebrates. Since the cerebrum is concerned with the process of learning and reasoning, the mammals can probably be considered the smartest animals on the earth. The cerebrum has complex folds in the higher mammals which increase its efficiency, for the outer gray matter of the cerebrum is the functional part and when the outer part folds inward the amount of gray matter is greater than it would be otherwise. Man has by far the largest cerebrum and it bears more convolutions in proportion to his size than that of any other mammal.

No Cloaca. The amphibians, reptiles, and birds have a cloaca, which is a cavity at the terminal end of the intestine into which the wastes of digestion as well as the urogenital products are emptied. Thus, the anus serves as the external opening for all of these. In the embryonic mammals a cloaca is formed, but tissue grows between the anus and the openings of the urogenital system, so that there are separate openings in the adult. The first order of mammals is an an exception, however, and does possess a cloaca as an adult.

Order—Monotremata

This order includes the most primitive of the mammals. They have hair on their bodies, mammary glands, and other characteristics that cause them to be classified as true mammals, but they have a cloaca and lay eggs like the reptiles and birds.

The little **duckbill** of Australia is one of the few examples of this interesting order of mammals. It has a bill like a duck, fur like a seal, webbed feet like a frog, and barks like a dog; it seems to be made up of odd parts of other animals. The female lays eggs which have shells like birds' eggs. She makes an underground nest lined with dried grass and the young hatch out after a short period of incubation. There are no

nipples to the mammary glands, but the ventral surface of the body is covered by a broad milk field. When lunch time arrives the mother lies on her back and the young crawl on her abdomen and lap up the milk that flows out from the pores of the skin.

Courtesy New York Zoological Society

FIG. 28.2. The odd little duckbill of Australia seems to be made up of odd parts of other animals. It is the most primitive mammal, laying eggs like birds.

Photo by Winchester

FIG. 28.3. A young opossum.

Order—Marsupialia

The marsupials are advanced over the monotremes in some respects, but are primitive in a number of their characteristics when compared with the other mammals.   There is no cloaca in the adult—openings of
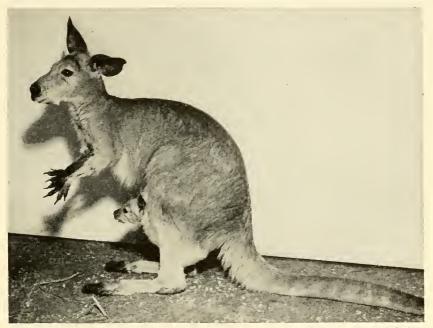
FIG. 28.4.   Young opossums in the pouch of their mother.   These baby "possums" are less than a half inch long and each one's mouth has fused onto a nipple of the mammary glands.   They were "born" three days before this picture was taken.

the anus and the urogenital tubes are separate.   The mammary glands have well developed nipples, and there are special muscles to pump the milk down the throats of the nearly helpless young.   The eggs are large and, in most species of marsupials, contain all the food which

will be used by the embryos until they can nurse. There are a few species in which rudimentary placentae are developed, but these accomplish little in the way of nourishment.

The **opossum** is one of the best known of the marsupials. It is very abundant in our southern states and furnishes the main dish at many a rural dinner of "possum and taters." The opossum eggs are retained

Fig. 28.5. A female kangaroo with a baby in its pouch. Like other marsupials a large part of the embryonic development takes place in the pouch of the mother. However, in the kangaroo the young are carried in the pouch at times after they have completed their embryonic development .

in the uterus until they hatch, which is only thirteen days after fertilization, so the young are very tiny and in an early embryological stage of development. They will be no more than half an inch long, but have sharp little claws by means of which they climb up the mother's body and enter the pouch on the ventral surface of her body. There they find the nipples and each little opossum grabs a nipple which he sucks down his throat and his mouth actually grows onto the nipple. When they have completed their embryonic development they leave the pouch, but clamber back in to nurse or when there is danger.

The **kangaroo** and the cuddly little **koala** "bear" of Australia are other well-known marsupials.

Courtesy New York Zoological Society

Fig. 28.6.   The koala bear of Australia, a marsupial.   As the young get too large to get in their mother's pouch they often ride on her back.

Order—Insectivora

These little animals that derive their name from their insect-eating habits have a placenta and the true viviparous reproduction as do all the rest of the orders of mammals.   Their teeth have an outgrowth near the base which protect the gums from the hard parts of insect bodies.

The little **mole** shows how animals may be adapted to their living conditions.   Moles spend most of their waking hours burrowing along under the ground in search of insects that may be there.   They especially

like to go down a freshly planted garden furrow because the burrowing is easier there; the fact that they uproot the plants growing there is only incidental. They have powerful front legs with sharp claws, and they move along underground with the same movements that a person uses to swim the breast stroke under water. Their eyes have become degenerate and the eyelids remain fused together throughout life. The external ears also are covered with skin. Both of these adaptations have persisted because they have survival value—they keep dirt out of these organs.

The **shrew** is an animal which has been described as the fiercest animal in existence, ounce for ounce. Shakespeare showed that he knew his biology when he selected the title, "The Taming of the Shrew,"

Photo by Winchester

FIG. 28.7. A mole. These highly specialized mammals spend most of their lives underground. Their front legs are developed for digging and the eyes and ears have no external openings so they will not get dirt in them.

for his clever comedy. The shrew is the smallest of the mammals and is about as small as any warm-blooded animal can be. The smaller the mammal, the greater is the exposed body surface in proportion to its size and the more it has to eat to keep warm. When a tiny shrew is placed in a cage with a mouse which is many times larger, the mouse will be so terrified that it will allow the shrew to eat it with hardly a token resistance. A shrew must eat about one and one-half times its body weight per day in order to live. Think of a person eating 225 pounds of food per day and you can appreciate the problems facing the shrews in finding and digesting sufficient food to keep alive. A shrew will die of starvation in a few hours if it is deprived of food.

Order—Chiroptera

This order includes the **bats,** which are the only flying mammals. We speak of flying squirrels, but they only glide. The finger bones of the last three fingers of each hand are greatly elongated and skin is stretched between the fingers to form the wings. The first two fingers terminate

FIG. 28.8. A bat. The skin is stretched between the bones of the fingers to form wings. The first two fingers terminate in claws which are used to suspend the animal while it is sleeping during the day.
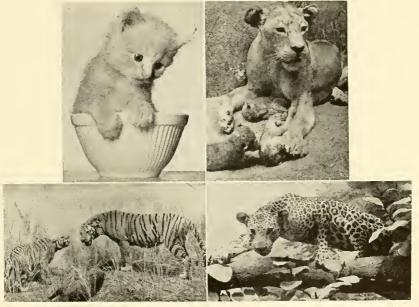
in claws which the bats use to suspend themselves upside down while they are sleeping during the daytime. Bats come out at dusk and fly around during the night in search of insects. It is an amazing sight to see the bats come circling up out of Carlsbad Caverns by the thousands every evening. Bats orient themselves and avoid collisions with trees, buildings and other objects by giving out shrill cries that are higher in pitch than the human ear can hear. As the echoes of their cries come

back to them they know the nearness of solid objects and can avoid them.

Not all bats eat insects. The vampire bats of the tropics will bite a person or other large animal, such as a cow, and lap up the blood as it flows out. In England there is an old superstition that there are some people that turn into bats by night and go around sucking blood. Such people are called vampires.

Order—Carnivora

These are the carnivorous mammals that include meat as an important item of their diet. Most of them are predatory and have strong

Photos by Winchester

FIG. 28.9. Cats. Even though it be a cuddly little kitten in a bowl or the huge lions, tigers, or leopards of the jungle, all bear distinctive characteristics in common that place them in the cat family.
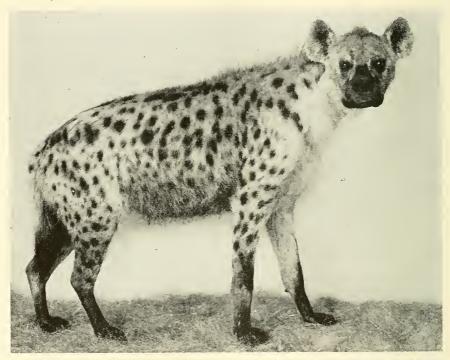
agile bodies, with sharp claws and teeth ; all are adapted to catch and kill animals of prey. All of their teeth are pointed, an adaptation for cutting and tearing flesh ; they have no teeth for chewing, so the food is cut up into small chunks and swallowed.

The Cats. The members of this family are easily recognized by their similarity to the familiar house cat. They include the lions, tigers,

leopards, pumas, wild cats, house cats, and similar animals. They are adapted to stalk their prey and then pounce upon them with one sudden burst of speed and, as a rule, are not capable of long sustained high speed.

The Dogs.   The dog-like carnivores often depend on running their prey down in a long chase in contrast to the cats. The wolves, foxes, and coyotes are included in addition to our common dog.

Courtesy Chicago Natural History Museum

FIG. 28.10.   The spotted hyena. A scavenger that lives off the remains of the prey killed by the other large carnivores. It has very powerful jaws for crushing bones.

The Hyenas.   These strange looking animals ordinarily do not kill their own prey, but wait for some of the bolder carnivores, such as the lions, to do the killing. Then when the lion has eaten his fill they come in and devour what is left of the carcass. They have the strongest jaws of any mammal and can easily crush large bones with their teeth.

The Raccoons.   These little carnivores are found near the water and often catch crayfish, fish, and clams for food. They seem very particular about their eating, for they thoroughly wash their food before eating it if water is available. This habit, however, seems not so much to be

cleanliness as it is an aid to swallowing. The salivary glands are not well developed, and the food is more easily swallowed when wet. They have delicate little hand-like front paws which they use to handle the food while washing and eating it. They tame easily and many a boy has had a pet coon, but, pet or not, coons still like chickens and it is a

Courtesy Chicago Natural History Museum

FIG. 28.11. A raccoon.

Courtesy Chicago Natural History Museum

FIG. 28.12. Giant pandas. These rare animals live high in the mountains of Tibet, but are well known in the United States because of the many stuffed toys made to resemble them.

little too much to expect them to know that chickens are a special kind of bird that should not be killed. The rare, but well-known, pandas from the mountains of Tibet are in the raccoon family.

The Civet Cats. The civet cats are found in oriental countries and the mongoose of India is one of the group. The mongoose is known for its ability to fight and kill cobras. It is not immune to cobra poison, but is so quick that it can tease a cobra into striking and dart in and grab it back of the neck before the cobra can get back into position to strike again.

Courtesy Chicago Natural History Museum

Fig. 28.13. A mink. This bloodthirsty little carnivore has a very valuable coat.

Courtesy Chicago Natural History Museum

Fig. 28.14. The badger.

The Musk-Bearing Carnivores. The skunk is the first animal thought of when animals with an odor are mentioned. It bears special musk glands which can eject an odor, there being none more odoriferous. Confident of this protection, the skunk goes serenely on its way through the forests and is usually given a wide berth by all the other animals. Should some inquisitive animal be rash enough to come too close, the skunk will first raise its tail and wave it as a warning signal, then will give a little jump with its hind legs and squirt a few drops of its musk at the intruder. That will be the last time that intruder will molest any animal even faintly resembling a skunk.

There are many others in this family that do not have such a pronounced odor and do not throw their musk. They are a blood-thirsty group including martens, minks, badgers, ermines, sables, weasels, and otters. In spite of the rather nauseating odor of some of the live animals, they possess some of the most valuable furs on the market.

The Bears. These are the largest of the carnivores. They are more omnivorous in their diet than most of the order and have teeth adapted

Photo by Winchester

Fig. 28.15. American black bear. It is impossible to go far in Yellowstone Park without meeting black bears that come to your car begging for a handout.

to do some grinding. The black bears of North America are the ones most commonly seen. No one can make a trip to Yellowstone Park without seeing the black bears, which visit the garbage cans in the camps and wait along the highway for handouts from passing cars. They seem to be very tolerant toward the many tourists and their inevitable cameras, but occasionally people will get bitten when they take undue liberties with the bears and forget that these are wild animals. The brown bears and cinnamon bears are only different color phases of the black bear, just as we have the blondes, brunettes, and redheads in human beings.

The grizzly bears are also found in the park, but are not bears to be fooled with, for they are quite dangerous. Fortunately, they stay away from people and are seldom seen along the highways or in the camps. They get their name from a silver ring that is found around each hair that gives them a grizzled appearance.

The Aquatic Carnivores. Like the whales, this is another group that is modified for life in the water, although they may spend considerable time out of the water. Fish provide the main item of their diet. They are masters at diving and swimming under water. The sea lions are the most commonly seen of the group. No zoo of any size is complete without a sea-lion pool, where these interesting creatures seem to get great enjoyment in showing off for the crowds. The trained sea lions

Fig. 28.16. Pacific walrus group. These large aquatic carnivores are found in the arctic regions of the Pacific.

of the circus show that they are experts at balance and can be taught to do many intricate tricks if the keepers' supply of fish holds out. The walruses are larger than the sea lions and live primarily in arctic regions. They are distinguished by their mustaches and the large tusk-like canine teeth that protrude from their upper jaws. The seals are also found in cold climates, but are well known as the source of seal-skin coats.

Order—Ungulata

Members of this order are characterized by the highly developed grinding teeth in their jaws, which is an adaptation to their herbivorous diet; and the presence of hoofs. Most of them stand on the tips of their toes with their heels never touching the ground. This makes it appear as if they have three joints in the legs rather than the two found in other

vertebrates. The toenails, which formed the claws of the carnivores, are enlarged to produce the hoofs.

The Odd-toed Ungulates. The horses are the most abundant of this group. They use only one toe on each foot, which is greatly enlarged. This is the third, or middle toe, but rudimentary second and fourth toes can be seen higher up the leg, although they do not touch the ground. There were ancient prehistoric horses that used four toes and more recently those that used three toes. A fairly complete history
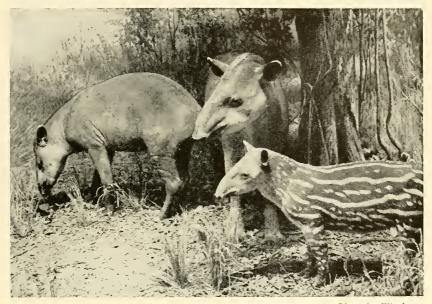
Photo by Winchester

FIG. 28.17. The American tapir, found in tropical South America, is one of the odd-toed ungulates and a close relative of the horses. This family group from habitat scene in the Chicago Natural History Museum.

of the development of horses has been worked out from fossils. This is discussed more fully in Chapter 34. The donkeys and zebras are very similar in their structure to our modern horse.

The tapirs are also placed in the odd-toed group, but they have four toes on the front feet and three on the hind feet.

The rhinoceros is a well-known ungulate that has three toes on both front and hind feet. They have one or two "horns" coming out of the median dorsal region of the head. These are not true horns, but are formed by a massing and fusion of hairs in this region.

The Even-toed Ungulates. Most of these ungulates use two of their toes, the second and third, which are incompletely fused together to form

FIG. 28.18.   Rhinoceros.   The huge "horns" are not true horns but are formed by a fusion of hairs.   This specimen has a tick bird perched on its back.   (From habitat group in Chicago Natural History Museum.)

the hoof.   They are often spoken of as the animals with a cloven hoof because of the slit between the two toes.   There is one group of the even-toed ungulates which have a special four-chambered stomach. Animals in this group are known as ruminants.   They can swallow their food rapidly when they may be grazing out in an exposed place and store this food in a chamber known as the rumen.   Then they can retire to a protected place where they can chew the food in leisure.   The second chamber, the reticulum, forms a mass of this unchewed food, and it is then regurgitated a mouthful at a time and chewed thoroughly before being swallowed a second time.   This time it goes into the third chamber, the psalterium, which is filled with folds that strain out the larger particles and return them to be chewed some more.   The well-chewed food passes on into the last chamber, the abomasum, which is the true stomach where the digestive glands are located.   Such animals are said to chew a cud.   There is an old superstition which holds that a cow must chew a cud in order to be contented and that she will die if she loses her cud.   Many a cow has been given a ball of rags to chew on when an owner thought that she had lost her cud.   In the ruminants
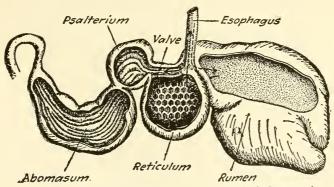
we find cattle, deer, elks, antelopes, goats, sheep, giraffes, camels, and llamas.

Those even-toed ungulates which are not ruminants include the hogs, peccaries, and the hippopotamus. The latter uses four toes on each foot. Even our common pig has four rather well-developed toes, but the second and third are usually the only ones that touch the ground.

Photo by Winchester

FIG. 28.19. Mother and baby doing fine. This mother hippopotamus and her week-old baby are representatives of the even-toed ungulates; they use four of their toes, and are thus kin to cattle. These are in the Brookfield Zoo in Chicago.

Animal Biology, Wolcott, McGraw-Hill Book Company, Inc.

FIG. 28.20. The complex stomach of a ruminant such as a cow. When first eaten the food passes into the rumen; later balls of this food, called the cud, are passed into the reticulum and up to the esophagus back into the mouth for thorough chewing. On the second swallowing the food passes into the psalterium and on to the abomasum for the initiation of digestion.

Order—Cetacea

This group includes the **whales, porpoises,** and **dolphins.** Whales are sometimes thought of as fish because they live in the water and have a body that is somewhat fish-like in shape. However, they are warm-

blooded, have a placenta, nurse their young with mammary glands after birth, breathe by lungs, and have the other typical mammalian characteristics. The tail is horizontal, rather than vertical, as in fish. This makes them swim with an up and down rolling motion in contrast to the side-to-side movements of the fish.
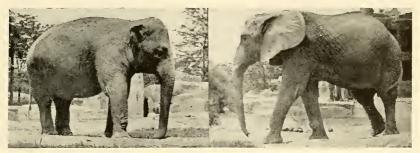
The whales have the distinction of being the largest animals that ever existed. One measured 103 feet long, and weighed the tremendous amount of 294,000 pounds. Whales have a heavy deposit of fat, or blubber, under the skin that gives them a good insulation from the cold waters in which they are often found. Unfortunately, for the whales, this blubber furnishes commercially valuable whale oil and so they are hunted by whaling vessels. Also, they may have an extremely valuable substance, ambergris, in the intestine from which the most expensive perfumes are made. Some species have long strainers in their mouths called whale bone, which, in the past, was used extensively as stays in women's corsets, but changing styles in feminine figures and other means of control of body parts that bulge in the wrong places have about eliminated their use in this respect.

The whales have their single nostril on the top of the head. They may be seen "blowing" at a great distance. This spout, which can be seen coming up from the nostril, is formed of condensing moisture and is not a spout of water. If the outside air is cool, the warm air from the lungs will condense and form a visible water vapor, just as a person's breath condenses on a cold day.

The porpoises are just a miniature edition of the whales, their structure being about the same. They are an interesting sight following in the wake of boats with their rolling motions, and sometimes they jump entirely out of the water.

Order—Proboscidea

The only living members of this order are the **elephants,** which are the largest of the living land animals. There are two varieties: the African elephant, which may be eleven and one-half feet tall at the shoulders and has huge ears that completely cover its shoulders; and the Indian elephant, which may be ten feet high and has smaller ears. In spite of their huge size they are rather easily captured and tamed and become valuable beasts of burden in tropical countries. In some parts of India, travel by elephant is the only way a person can get through a dense jungle. The tusks, which may be more than eleven feet long in the African elephant, are a valuable source of ivory.

Photos by Winchester

FIG. 28.21. Indian elephant on the left and African elephant on the right. These pictures show the differences between these two kinds of elephants. These specimens are found in the Brookfield Zoo.

Photo by Winchester

FIG. 28.22. A mermaid. This ugly sea cow is the true mermaid, although it is a far cry from the beautiful damsels that we associate with the name. Mermaids live in the water and come to the surface only to breathe, but are true mammals. (Reconstruction of under water habitat at the Chicago Natural History Museum.)

The woolly **mammoths,** whose bodies have been found in a nearly perfect state of preservation in Siberian ice fields, were the prehistoric relatives of our modern elephants. Apparently these were the only members of the elephant family that have been capable of living in cold, arctic regions. When some of these were found the flesh was so well refrigerated that it was actually fed to dogs and at a banquet in London mammoth steaks were served which had been in a deep freeze of Siberian ice for several thousand years. The tusks were sold for ivory. Still more ancient were the **mastodons,** which are believed to have lived in lush, tropical rain forests.

Order—Sirenia

Sometimes exhibits are set up at carnivals and circuses to allow the public to gaze on a real live mermaid for a small fee. With visions of a beauteous female creature, human-like from the waist up and fish-like from the waist down, the ever-gullible people buy their tickets. To say that they are disappointed is putting it mildly, when they walk in to see an ugly **sea cow** floating lazily in a tank of water. However, the sea cows are the real mermaids, although only a drunken sailor on a dark night could mistake them for the mythical sirens that give this order its name. They are found along the Atlantic coasts of Africa and South America and are numerous along lagoons of the Florida coast. Their bodies are adapted for life in the water with the front legs modified into flippers and the hind legs absent. The tail is broadened and flattened out to form a fin-like structure for swimming.

Order—Rodentia

This is the largest order of mammals, having more genera and species than any other, and it probably contains more individuals than all other orders of mammals combined. These mammals have many enemies, such as the snakes and birds, but they are extremely prolific in reproduction. They mature rapidly and the females have large numbers of offspring at frequent intervals during their lifetime. Mice will be ready for reproduction within three months after they have been born, have a gestation period of only twenty days, and have an average of about eight offspring every six weeks. Rodents are omnivorous in their diet and are man's chief competitor among the mammals for food. In fact, their diet is so nearly like that of man that they are almost always used in dietary experiments to determine the effects of the elimination of important elements in the human diet. Rodents have no canine teeth, but the

incisors are long and curved. This is the most easily recognized characteristic of the group. The teeth continually grow from their roots and the rodents wear them down on the ends by gnawing on hard objects, so they will not become too long. The beavers are even able to gnaw down trees.

The Squirrel-like Rodents. This large group includes the squirrels, ground squirrels, flying squirrels, chipmunks, gophers, ground hogs, prairie dogs, beavers, and others. The beavers are the largest rodents in the United States. They gnaw down trees and place them across streams to form dams. Cracks between the logs are filled in with

Photos by Winchester

Fig. 28.23. The beaver. This large rodent gnaws down trees which are used to build dams across streams. The broad, flat tail acts as a support while gnawing and is also valuable as a rudder while swimming.

mud. Then they build their homes over the lakes which are formed above the dams. These homes are above the water line, but have only underwater entrances. Thus they serve as an excellent retreat from enemies. The beavers are beneficial because these dams act as an aid in controlling erosion; but the popularity of their fur threatened their extinction before protective measures were put into effect.

The Rat-like Rodents. These are the many species of rats and mice which are so abundant the world over. They do tremendous damage to the food supply, during its growth and after it has been harvested and placed in storage. They also help spread some of the world's most serious diseases, such as bubonic plague and typhus.

Other Rodents. Porcupines have developed long, stiff, sharp-pointed hairs which have special muscles which can make them stand erect. Although they cannot throw their quills, as is sometimes believed, there is a special mechanism to release the quills when they become stuck into another animal, and many a coon dog has come away from an attack on a porcupine with quills embedded in his nose and mouth. The guinea pig is another very well known rodent. The chinchilla is a beautiful little rodent with very fine and soft fur. Chinchillas have been imported into the United States from the mountains of Chile and Bolivia where they have been all but exterminated by trappers. Hundreds of chin-

Fig. 28.24. A chinchilla. These rodents have a very fine and soft fur and are raised extensively for their fur.

chilla ranches have been started in the last few years with breeding pairs often selling at prices ranging from $1,000 to $1,500. As yet the population has not reached a point where the chinchillas can be killed extensively for their pelts. When this point is reached they will probably be used widely for fur capes and trimmings. The fur is delicate and may not prove practical for entire coats. Without doubt they will be much cheaper as their numbers increase, because they are relatively easy to raise and inexpensive to keep.

Order—Lagomorpha

This order includes the **rabbits.** They were formerly placed in the order *Rodentia,* but recent studies indicate that they have certain distinctive characteristics which warrant their inclusion in a separate order. They
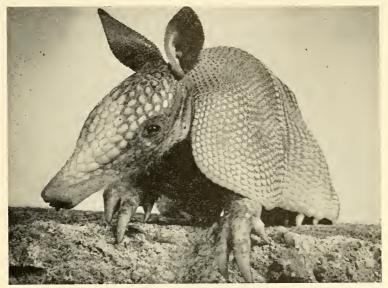
Photo by Winchester

Fig. 28.25.   An armadillo.   Note the heavy protective skin that covers the body and the powerful digging claws.

Photo by Winchester

Fig. 28.26.   Ant bears.   These animals, found in tropical South America, are in the order Edentata and thus closely related to the armadillo.   These ant bears in the habitat group in the Chicago Natural History Museum are shown feeding on termites from a nest which they have opened with their powerful claws.   An ant bear, having no teeth, extends its long, slender tongue into the termite nest.   The termites stick to the tongue and are carried into the small mouth, where they are swallowed.

have gnawing teeth, but there are two rows of these teeth rather than a single row as in the rodents. Also, detailed seriological studies have been made of the blood of the rabbits in comparison with the rodents, and the results of these tests indicate that the relationship of the two groups is not close enough to warrant their inclusion in one order.

Order—Edentata

This order name means without teeth. Some have small jaw teeth, but they have no enamel and no roots.

The Armadillos. The skin of the armadillo bears bony plates that make this one of the few vertebrates that have an exoskeleton. When the armadillo rolls itself up into a tight little ball, it is about as well protected as the tortoise. Food consists primarily of insects and the stout legs and sharp claws of the armadillo are perfect equipment for digging the insects out of the ground.

The Sloths. These strange creatures, somewhat like longhaired monkeys in appearance, are found in the jungles of Central and South America. They spend most of their lives hanging upside down from the limbs of trees and possess long, curved claws that can be hooked over the limbs for support. Their food consists primarily of leaves which furnish them nourishment and also sufficient water so that they do not have to descend to drink. When one is placed on the ground it makes a ludicrous sight as it awkwardly pulls itself along in this unaccustomed position.

The Ant Bears. These animals live primarily on ants and termites. They have powerful legs and claws to dig open the nests and a long sticky tongue which they put down in the opened nest. When the insects are stuck to it the tongue is withdrawn into the mouth and the insects are swallowed.

Order—Primata

The most intelligent of the mammals are included in this order. The cerebral hemispheres are very large, and the surface is greatly convoluted. These are features which are correlated with great mental capacity. Instead of claws or hoofs, they have nails on the tips of their fingers and toes. Most of them are arboreal animals with their hands and feet adapted for grasping, a characteristic which enables them to swing from limb to limb. This grasping ability also makes them very adept at handling things, and the hands rather than the mouth are used for picking up many objects. The eyes of primates are on the front of

the face and images seen by the two eyes are superimposed. This gives binocular vision, that is, both eyes see the same thing, but from slightly different angles which gives depth to images and aids greatly in judging distances. The three-dimension movies show how much more natural things appear when seen with depth. The arboreal habits are closely correlated with this accurate eyesight, for it would hardly lead to sur-

Courtesy Chicago Natural History Museum

FIG. 28.27. Sportive lemur. The lemurs are the most primitive of the primates.

vival if a primate jumped for a limb only to find that he had miscalculated the distance. We see tiny details with our eyes far better than lower mammals due to the development of a spot of clearest vision, called the fovea, in the center of the retina. In other mammals smell is often the dominant sense—a dog recognizes his friends by smell rather than by sight and some dogs have even learned to follow the scent of an animal while running at a high speed. The sense of smell, on the other hand, is very poorly developed in the primates, although

many of us become very fastidious about the odors around us and complain about bad odors, such as the rotten egg odor of hydrogen sulfide permeating the atmosphere of a school from the chemistry laboratory.

The primates have a single pair of mammary glands located in the pectoral region of the body. This is correlated with their upright sitting

Courtesy Chicago Natural History Museum

FIG. 28.28. A woolly monkey from Ecuador. This typical new world monkey is shown using its tail as a fifth prehensile limb.

position, so the young can nurse without standing on their heads. The young are born with a strong grasping instinct and, in most primates, cling to the mother's body while she leaps around in the trees. Even the human baby is born with this instinct and can grasp a limb strongly enough to support its own weight a week or two after birth, but after this the strength is lost and an older baby cannot thus support its body weight.

The **lemurs** are the most primitive of the primates. They are timid little animals found in tropical jungles, that look something like a cross between a cat and a monkey. Some of them bear a claw instead of a nail on the second finger.

Many tropical regions of the world have swarms of **monkeys** filling the trees. The monkeys of the new world often use the tail as a fifth leg and can swing from a tree by the tail just as they can by their legs

Photo by Winchester

FIG. 28.29. Mother gibbon and baby. Young apes are born with a strong clinging instinct that enables them to hold to the mother while she swings from limb to limb in the jungle.

or arms. One of the New World monkeys is familiar as the cute, somewhat timid, little capuchin monkey that accompanies the organ grinder. These monkeys can be taught to do many tricks that usually bring them coins as a reward. The Old World monkeys are built more stockily then the slender New World monkeys and have a large calloused pad on which they sit. The rhesus monkey is the best known of this group. This monkey came into prominence recently when it was discovered that about 85 per cent of the people have a factor in their blood that is found

in this monkey. We call this the rhesus, or shortened to rh, factor; persons having it are called rh positive; those not having it called rh negative. It is inherited and a baby that inherits the rh factor from its father may develop a serious blood condition when he has an rh negative mother.

The Apes. These are the most man-like of all other animals. The arms are considerably longer than the legs, so they walk in a semi-
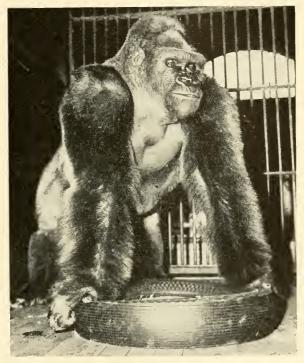
Courtesy Chicago Natural History Museum

FIG. 28.30. Orangutan. Facial expression of the orang is very human-like. They have such long arms that their fingers almost touch the ground when standing upright.

upright position touching their knuckles to the ground for balance as they go. However, their feet are more adapted for grasping than walking and they walk primarily on the outside edge of the foot. This gives them a characteristic shuffling, bowlegged gait. They do not have a tail as adults but, like man, have an embryonic tail and rudimentary tail vertebrae in the adult.

The gibbons, found in the Malay region, are the smallest and most primitive of the apes. They do not reach a height of more than three

feet.   Brain capacity is often used as an index of intelligence, and from this standpoint the gibbons are far below the other apes and man.   They have a capacity of only 90 cc. on the average.   A modern civilized man, on the other hand, has a capacity of about 1500 cc., but there is a primitive race, the Australian aborigines, which have a brain capacity of only 1200 cc.   Of course, some allowance must be made for the smaller size

FIG. 28.31.   A gorilla.   Although among the most powerful of animals, gorillas are hard to keep in captivity because they are susceptible to many human diseases.   This is Bushman at the age of seventeen in the Lincoln Park Zoo in Chicago; he died a few years later.

of the gibbon.   In one respect, however, they are more man-like than the other apes.   They walk erect without touching their arms to the ground, but holding them out to their sides as balancers.

The orangutans of Borneo and Sumatra are probably more human-like in facial features than any of the group.   There is no development of the heavy brow ridges, which may give other apes a somewhat ferocious appearance.   Hair on the face grows in the same region that it does on man's face and a portrait of an orangutan, at first glance, might

be mistaken for a bewhiskered old man. In the old days, many a person paid good money at the circus to see the "wild man of Borneo," which was only an orangutan. In an upright position, however, the similarity ceases; the fingers almost touch the ground. Such long arms give them a very comical appearance, but care must be taken at the zoo, for they can reach through the bars of a cage for an unbelievably long distance. They reach a height of about five feet and have a brain capacity of 500 cc.

The chimpanzees, found widely distributed in Africa, attain a height of about five feet, and have a brain capacity of 500 cc. They are tamed easily and when young seem to enjoy human company, but the adults seem to realize that people are just trying to "make a monkey" of them and resent it. This makes the adults quite dangerous. Experiments show that they have a reasoning power, for they will stack boxes in order to secure food suspended out of reach. They can be taught to do many simple tricks that make them a feature attraction at the zoo or circus. They can dress themselves, eat with a knife and fork, ride a bicycle, waltz, and do acrobatics that put human efforts to shame. They are among the most popular of the movie and TV actors because of their great appeal to audiences of all ages.

The gorillas are the largest of the primates. They grow to a height of six feet and weigh up to 600 pounds. They have a ferocious appearance and a disposition that goes with it. This, coupled with their great strength and cunning, makes them among the most dangerous animals to deal with. They have a brain capacity of 630 cc. Young gorillas have been tamed, but no person is foolhardy enough to enter a cage wth an adult.

Gorillas can be found only in the highland regions of Africa today, for those living in lower altitudes have been killed out. The hunter may become the hunted in these regions, for the gorillas sometimes hide along the trails and allow a group of people to file past and then grab the last person in line. They seem to realize that it would not be good policy to grab one in front, for the others would then be in position to attack. In spite of their huge size and great strength, they are among the most difficult of animals to keep in captivity, for they are susceptible to the many respiratory ailments that affect people. A circus kept two gorillas alive for several years by keeping them in special air-conditioned cages with the air filtered free of germs, but both died in spite of these precautions.

Man is the most highly advanced of the primates. We have attained a dominant place in the animal kingdom because of the high degree of development of our cerebrum. Physically we are weaklings; a chimpanzee, by actual measurement, has strength in his biceps several times

that possessed by man, yet his biceps is smaller in size. It is only by our superior intelligence that we are able to survive in a world where competition is so keen.

Classification and Derivation of Scientific Words

Phylum Chordata (Cont.)

 Class G. Mammalia (L. *mamma,* breast; nourish their young by means of mammary glands on the breast).

  Order 1. Monotremata (L. *monos,* one; *trema,* hole; have only one posterior opening of the body, or a cloaca). The duckbill.

  Order 2. Marsupialia (L. *marsupium,* pouch; have a pouch in which they carry their young). The opossum and kangaroo.

  Order 3. Insectivora (L. *insectum,* an insect; *vorare,* devour; insect-eating animals). Mole, shrew, hedgehog.

  Order 4. Chiroptera (Gr. *cheir,* hand; *pteron,* wing; the hand has been modified to form a wing). The bats.

  Order 5. Carnivora (L. *carnis,* flesh; *vorare,* devour; flesh-eating mammals). The cats, dogs, hyenas, raccoons, civet cats, skunks, bears, seals, sea lions, and walruses.

  Order 6. Ungulata (L. *ungula,* hoof; bear hooves on their feet). Horses, tapirs, rhinoceroses, pigs, peccaries, hippopotami, cattle, deer, antelopes, goats, sheep, giraffes, camels, and llamas.

  Order 7. Cetaceae (L. *cetus,* whale). The whales and porpoises.

  Order 8. Proboscidea (Gr. *pro,* before; *boscein,* feed; bear a long proboscis on the front of the head used in feeding). Elephants.

  Order 9. Sirenia (Gr. *siren,* a mermaid; members of this order bear little resemblance to the mermaids). The sea cows.

  Order 10. Rodentia (L. *rodare,* to gnaw; these are gnawing mammals). The squirrels, rats, porcupines, etc.

  Order 11. Lagomorpha (Gr. *lagos,* a hare; *morphe,* form). The rabbits and hares.

  Order 12. Edentata (L. *e,* without; *dentis,* tooth; these are the so-called toothless mammals, although some of them have small jaw teeth). The armadillos, sloths, and ant bears.

  Order 13. Primata (L. *primatis,* first; so named because this is considered to be the first of the animal groups in importance). The lemurs, monkeys, apes, and man.

REVIEW QUESTIONS

1. Give the characteristics of the mammals.
2. What is meant by a cloaca and what is its relation to the mammals?

3. What are the reasons for considering the duckbill the most primitive of the mammals?

4. How are the Marsupials advanced over the Monotremes yet more primitive than the other mammals?

5. What factor seems to limit the minimum size of mammals?

6. How does the cat family differ from the dog family in methods of capturing prey?

7. If you were shown the teeth from a rodent, a carnivore, and an ungulate, how could you distinguish one from the other?

8. How is the complex stomach of the ruminants an adaptation for protection?

9. How are whales adapted for their life in cold waters?

10. What are the economic importances of the beavers?

11. Name the three kinds of primates.

12. How does walking in the apes differ from walking in man?

13. What are the functions of the four kinds of teeth in mammals?

14. What three diverse groups of animals are found in the Edentata?

15. Compare the sea cows with the whales.

16. Can you think of any reason why the largest aquatic animal should be larger than the largest land animal? If so explain.

17. Compare the brain size of the gibbon, orang, gorilla, and man.

18. What is the hoof difference between the even-toed and the odd-toed ungulates?

19. How are the Chiroptera adapted for flight?

29

The Distribution of Animals

Now that we have completed a survey of the different kinds of animals that inhabit the earth we shall turn our attention to some of the problems of distribution. Why do kangaroos live in Australia and not in India; why are there no elephants in South America; why do some animals imported into a strange environment die out rather quickly while others multiply and become a part of the fauna of the new region? These are some of the interesting questions which are answered in a study of zoogeography, animal distribution.

The distribution of animals today is explained partly by their history in the geologic past. We know that individual species of animals are not found in all parts of the earth where they can survive. This is due in part to the fact that they have not had the opportunity to get into other regions of the world. When man, either purposely or accidentally, introduces them into a new, favorable environment, they often reproduce phenomenally. There were no rabbits in Australia before 1788, but at that time a number of rabbits were brought in by some Englishmen who thought they might make nice game for hunting. Since then they have multiplied until they have overrun the country and have become a serious pest. They are rounded up and killed by the thousands in efforts to keep them under control. The European starlings were introduced into New York City in 1890, and they multiplied so rapidly that they have now spread over the entire United States and Southern Canada. They roost in great flocks in our cities and make a general nuisance of themselves. The mongoose is a native of India where it is highly regarded because it kills many deadly cobras; but, when it was introduced into the island of Jamaica, it not only killed many snakes, but began destroying many of the other native animals.

Any species of animal will be found in all habitable portions of the earth if it can get there, if it can survive after it gets there, and if it does not change into a new species after it gets there. In general, the older a species, or a group of related species, is in geologic time, the more widely it will be distributed, because it will have had a longer time to reach the various parts of the earth. There are a number of important exceptions to this, however. There are some animals, for in-

stance, which were formerly abundant on the earth, but are now declining in numbers and may be facing extinction. These we often find existing only in the isolated regions where they have temporarily escaped the dangers which have exterminated those of their kind in other parts of the world. Such species include the egg-laying mammals of Australia, and the reptile, *Sphenodon,* which has a third eye on the top of its head and is now found only in a few islands off the coast of New Zealand.

The extent of the range of animals is also due to the means of dispersal available to the species. Strong fliers, such as the ocean birds, generally have a very extensive range. We have already learned how the arctic tern breeds in northern Canada and winters in the antarctic regions. Strong swimmers, such as the toothed whales, are often world-wide in distribution. Eels which breed in the Sargasso Sea near the Bermuda Islands migrate to the fresh-water rivers of several continents. Many protozoa are also world-wide in their distribution, because they often "hitch rides" in mud on the feet of migrating birds.

Barriers to Dispersal

Barriers of different kinds bar the way to animal dispersal. Let us examine some of these with respect to particular animals.

Geographical Barriers. Mountain ranges, deep valleys, oceans, and land may serve as barriers. These are transient barriers in terms of great geological eras, but can be very formidable barriers for considerable periods of time. The Rocky Mountains are high enough to block the movement of many animals and, as a result, the animals on the Atlantic Coast are very different from those on the Pacific Coast. The Alleghenies, on the other hand, are usually less than a mile above sea level at their highest peaks and there are many gaps through which animals can migrate. As a result, life on both sides of these mountains is very similar. They are high enough, however, to furnish an avenue for the southern migration of both plants and animals from Canada which extend their ranges southward as far as northern Georgia. On the tops of the Great Smoky Mountains there is a fir-spruce zone in which birds, typical of this zone in Canada, nest.

Land is a big barrier to both marine and fresh-water fish. Before the Panama Canal was built, the fish on the west coast of Panama were very different from those on the east coast even though they lived only a few miles apart. During the last forty years, however, a few have managed to move from one ocean to the other through the canal and are now established in a new ocean. Fresh-water fish are often confined to a particular drainage system and cannot cross the bridge of land into

another river which may be only a few miles away. Waterfalls often bar the progress of animals. Niagara Falls formerly kept the marine lampreys out of the Great Lakes; but, when shipping canals were built from the St. Lawrence River, the lampreys entered the Great Lakes and have become a serious menace to the fish.

By *LIFE photographer, George Skadding, Copyright TIME, Inc.*

FIG. 29.1. Lamprey eel attached to a large trout taken from one of the Great Lakes. This marine eel has found its way into the Great Lakes through ship canals which have been built from the St. Lawrence River.

Climatic Barriers. Tropical and warm-temperate animals are restrained from northward movements by the long, cold, and dark arctic winters. All the monkeys are tropical or warm-temperate—none inhabits the United States and only one is found in Europe and that is in southern Spain where a number of subtropical species are found. On

the other hand, the tropical heat and related factors form an impassable barrier for arctic and cold-temperate animals. The arctic fox, the polar bear, the snowshoe rabbit, and the reindeer are highly adapted for snow and ice and could not long survive in tropical jungles. The amount of rainfall is also important. Deserts, such as the Sahara which extends nearly all the way across northern Africa, form a barrier for most animals which cannot be crossed.

Ecological Barriers. An animal is limited in its range by the kind of food that it eats. The American buffalo, or bison, was a plains animal and rarely entered the eastern forests. Squirrels and woodpeckers, on the other hand, are confined to forested areas by the nature of their feeding and nesting habits. Any parasitic animal is limited to the same regions which are inhabited by its host, or by agents upon which it is dependent for its spread. The parasite of malaria has recently had its range in the United States greatly reduced by the control of the *Anopheles* mosquito. It is often difficult to determine the ecological factors which control range—a species may be common in one locality and rare or absent in another that appears to be equally desirable. There are some lungless salamanders which are confined to a very small range in the cold, damp slopes of the Great Smoky Mountains where it rains almost daily. Here their need for a very moist habitat is clearly the limiting factor that prevents their spread into the surrounding lowlands, but this hardly explains why they are not found on other slopes in the same mountains where there is an equally heavy rainfall. The parula warbler in Canada and northeastern United States nests almost exclusively in the Usnea lichen. In the southeastern United States it nests in the Spanish moss which is a seed plant in the pineapple family, but it resembles the Usnea lichen in appearance. The cottonmouth water moccasin is confined to the rivers and swamps of southeastern United States and occurs as far north as southern Illinois and western Kentucky. It is difficult to assign any reason why this snake does not occur in the numerous rivers and swamps farther north in Illinois and east in Kentucky. There seem to be no barriers that could keep it from these regions. A more thorough study will probably reveal some ecological barrier.

Aids to Dispersal

Now that we have surveyed some of the barriers to dispersal, let us now survey some of the aids to dispersal. Those animals which are capable of rapid locomotion on land, in water, or in the air will spread rapidly, but those that are more sluggish must depend upon other means of dispersal, as a rule. Mud taken from the feet of migrating birds has

been found to contain eggs and cysts of many small crustaceans and protozoans. Lice, ticks, and fleas hitch rides on their host animals. Clams, which move about very little as adults, produce larvae which attach themselves to the gills of fish and are carried great distances by these more active hosts. Many animals make their way downstream floating on logs and debris caught by the crest of floods. Even in the ocean there are currents which carry many sea animals for great distances. Winds play their part also. Hurricane winds in Florida bring salt marsh mosquitoes and other insects far inland. The beaches of the North Atlantic states may be covered with many thousands of Portuguese-men-of-war after a hurricane in the Atlantic has blown them in from the Gulf Stream. There are forty-four species of European birds that have been found in North America, apparently blown across the ocean, since many of them were found after a storm. In most cases, the animals which are dispersed in these ways do not become established in their new environment, but there is no doubt that such accidents do occasionally expand the range of animals.

Man has been one of the greatest aids to dispersal of animals, since he has developed means of rapid locomotion to all parts of the earth. Early explorers let some of their horses escape and these established herds of wild horses in the southwestern region of the United States. The Norway rat has been carried as a "stowaway" in the holds of ships to every port in the world. The European periwinkle clings to the hulls of ships and drops off in our own coastal waters. The Colorado potato beetle formerly lived on wild plants belonging to the potato family in the foothills of the Rocky Mountains. When man planted a bridge of potato plants all the way across the country, this beetle found a means of spreading all the way to the Atlantic Coast.

Man has deliberately introduced animals in many parts of the world. In Kentucky there are two wild life reservations into which the European red deer has been successfully introduced. In the Bernheim reservation near Louisville, the red deer have become so numerous that they damage farm crops and an open season was declared on them. The ubiquitous English sparrow was carefully introduced in several American cities in about 1860. It rapidly spread all over the United States and became an obnoxious pest, especially in the cities. With the passing of the horse the English sparrow has gradually become less common in the cities, for they do not thrive on the bolts and gasoline fumes as they did on the droppings from the horse. An introduced species often reproduces much more rapidly than native species because it has outdistanced its natural enemies, including many parasites and diseases. In recent years, whenever an insect pest has become established, the Bureau

of Entomology has sent biologists to the land from which it came to discover what factors kept it in check there. In some cases they have introduced a natural parasite which has brought it under control.

Land bridges, both past and present, which connect some of the continents are used by animals as migration routes. The Isthmus of Panama allows tropical forms from South America to move into Central America and Mexico; many monkeys have taken this route. It is known from geological studies that Alaska was connected with Siberia rather recently when the northern climate was much warmer than it is today. At that time there was an extensive migration of both animals and plants between the Old and the New World. As a result, the species and genera are very similar in eastern Asia and parts of North America, particularly the southern Alleghenies and the east coast. The rise of the Rocky Mountains and the development of great western deserts have changed life in the west far more than in the eastern part of the United States.

Migration of Animals

Sporadic Migration. These are the most spectacular migrations and create the most public interest. The snowy owl in North America migrates south in great numbers whenever their natural food, the lemmings, become scarce in the arctic regions. Their appearance in the United States always creates excitement. These owls have developed the habit of feeding during daylight hours on the arctic tundra where daylight lasts for months during the summer and where there are few other animals to molest them. When they come south, they continue feeding during daylight; but they are very conspicuous and are slaughtered by the hundreds by hunters and predatory animals.

In Scandanavia the lemmings gradually increase in numbers until they overpopulate the countryside. Many of them then start a mass migration. On this migration they swim rivers and cross mountains. When they come to the ocean they plunge in and swim until they drown. Some have referred to this as a mass suicide which they undergo as a means of keeping their population under control, but it seems much more likely that they set out in search of new places to feed and reproduce. When they come to the ocean they attempt to swim it as they have swum the rivers and perish in the attempt. According to a local legend, they are headed for the lost continent of Atlantis where they supposedly went in their migrations in the past.

Annual Migrations. Annual migrations are of many kinds and occur in a great variety of animals. In mountainous regions many animals move down into the valleys in the winter. We have already learned how

the salmon migrate up the rivers and spawn in the very streams in which they were hatched. Birds, of course, make the most extensive migrations. Most of the birds of the United States are migratory; although a few, including the bobwhite, the ruffled grouse, and the cardinal, are nonmigratory. The waterfowl, such as ducks, geese, and swans, are the most conspicuous of the migratory birds. By systematic banding the Fish and Wildlife Service had discovered that these birds follow four special routes, known as the Atlantic flyway, Mississippi flyway, Great Plains flyway, and the Pacific flyway. Many of our songbirds appear to have been derived from South American birds and to have come into the United States in the summer in search of a place to raise their young. The wood warblers are typical of this group. As soon as they have raised their young, they return to their ancestral home in South America at a time when the climate of the United States is still warm and food is abundant. Of forty-six species of wood warblers there is only one, the myrtle warbler, which regularly winters north of the subtropical portion of the United States. In contrast, the Old World warblers, represented in the United States by three species—the golden-crowned kinglet, the ruby-crowned kinglet, and the blue-gray gnatcatcher—may winter as far north as southern Canada. None of these three go as far as South America.

Some butterflies also have annual migrations. One of the best known of these is the monarch or milkweed butterfly. In the fall of the year they may be observed moving leisurely southward in great flocks. Unlike most butterflies they do not hibernate, lay eggs, or form chrysalids for over-wintering. The following spring they gradually move northward with the season.

Reduction in Range

One has only to examine a fossiliferous rock to discover many species of animals and plants which no longer occur in any particular region. Mastodons, mammoths, and camels were formerly common in the United States. Many animals are being reduced in their range today because of the impact of expanding civilization. Many of our game animals have been driven from all but a small part of their former range. The American buffalo, or bison, is now limited to a few herds in some of the western parks and a few specimens in various zoos of the nation. The whooping crane is reduced to a flock of about twenty birds, and the California Condor has become very scarce. The mighty sturgeon of the northern rivers has been caught so extensively for its roe, which is made into caviar, that it has become rare in most streams.

Australia has declared an embargo on the shipment of the rare duckbill. Even the alligator in Florida is on the decline, and laws protecting them have been passed.

Extinction is the end result of continued reduction in range. All of the dinosaurs became extinct in the Mesozoic Era at least 55 million years ago. The woolly mammoth became extinct only a few thousand years ago and with him went the great saber-toothed tiger which preyed upon the mammoth. Man has deliberately or accidentally exterminated many species during the last hundred years or so. The passenger pigeon
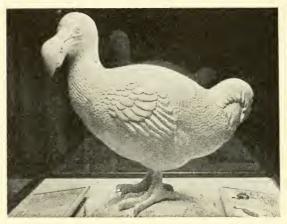
Photo by Winchester

FIG. 29.2. Restoration of the extinct dodo bird. This was a flightless bird which lived in great numbers on the island of Mauritius in the Indian Ocean. There was a great slaughter of these birds by man and his domestic animals when the island was discovered, and they have long since become extinct.

was the most abundant game bird in North America one hundred and fifty years ago. According to J. J. Audubon in 1813 he observed a continuous flight of these birds for three days. The people in this area fed on pigeons for a week at this time. The passenger pigeons nested in dense rookeries, one of which was described by Alexander Wilson in 1810 near Shelbyville, Kentucky. It "was several miles in breadth and upward of 40 miles in extent. In this tract almost every tree was furnished with nests wherever the branches could accommodate them." Many writers learnedly prophesied that the birds were so common that no amount of hunting could affect their abundance. Yet by 1898 the last nesting place had been broken up by market hunters and the great groups reduced to a few scattered flocks which made no attempts to nest. The last known passenger pigeon died in the Cincinnati Zoo in 1914.

Another interesting game bird, the heath hen, which was formerly common in the eastern states, had by 1921 been reduced to a small flock on Martha's Vineyard Island off the coast of Massachusetts. About that time a disastrous fire swept the island during the nesting season and is believed to have destroyed both the nests and the female birds that were incubating. All but one or two females and about a dozen males were killed. These survivors lived for a time on the island but all died without further reproduction.

The extinction of the dodo bird is another example of man's thoughtlessness in exterminating valuable animals. The dodo was a flightless bird belonging to the pigeon order which lived on the Island of Mauritius in the Indian Ocean. This large, heavy-bodied bird was so clumsy that the sailors killed it with clubs. Pigs, dogs, and other imported animals finished the extermination, and none were reported after 1681. We have the common expression "dead as a dodo" to remember them by. A few skeletons were dug up two hundred years later in a swamp on the island and mounted.

In 1741 a Russian whaler put in at one of the Aleutian Islands and a man named Stellar found a large group of seacows there. They were called Stellar's seacows. Within twenty-five years, however, the passing whalers had killed the last of these animals, and they have never been seen since.

Several species of river snails became extinct when the Norris Dam was built and flooded the Clench River. These snails had a very restricted range in the rapids of the river and could not survive in the calm waters of the lake.

Discontinuous Range

A number of species or groups of related species of animals have a peculiar distribution on the face of the earth which is difficult to explain without a knowledge of the geological record. The tapir is a hoglike animal found in Central America, South America, and Sumatra. The alligator is found only in central China and the southeastern part of North America. A lizard known as the skink is found in Southeastern United States, China, and Japan. The horseshoe crab occurs on the Atlantic Coast of North America and on the coast of the Molucca Islands in the East Indies. Marsupials are found in the Australian region and a few in the Americas, but not in between.

Related genera may also be interesting in their distribution. There are three known lungfish in the world; they are found in tropical South America, Africa, and Australia—as far apart as a world of this size will

allow. In this case we know from fossils that lungfish were formerly world-wide in distribution, and these represent three surviving relics.

Geographic Realms

Alfred Russel Wallace, the great explorer naturalist, divided the world into six geographic realms on the basis of the animal life. Great barriers such as the oceans, deserts or mountain ranges served to contain certain forms of life in these areas. These realms are as follows.

Australian Realm. This region includes Australia, New Zealand, Tasmania, and certain neighboring islands in the East Indies. A division known as Wallace's line separates this realm from the rest of the East Indies. The characteristic animals are the egg-laying mammals; the marsupials, such as the kangaroo, the koala bear, and the phalangers; and birds, such as the cassowaries and apteryx. Absent from this area are the higher mammals except man and his primitive dog, called the dingo. This realm has been divided from the rest of the world for a very long period and contains only the most primitive of the mammals. When new orders developed in the rest of the world they were unable to migrate to Australia.

Oriental Realm. This region includes southern Asia south of the Himalaya Mountains; in it we find India, southeastern China, the Philippine Islands, and the large islands in the East Indies north of the Wallace line. Characteristic animals are the orangutan, gibbon, Indian elephant, tiger, tapir, peacock, and the jungle fowl which is our domestic chicken. This is not as isolated as the Australian Realm and contains many animals in common with other parts of the world.

Ethiopian Realm. This region includes all of Africa south of the Sahara Desert. Madagascar, which has many unique animals, also belongs in this realm. The characteristic animals are the gorilla, chimpanzee, zebra, African elephant, giraffe, and hippopotamus.

Neotropical Realm. This includes South America, Central America, Mexico, and the West Indies. Characteristic animals are the New World monkeys, such as the marmoset and capuchin; sloths, the anteater, llama, peccaries, and the chinchilla. The great majority of hummingbirds are found in this realm and only a few species are found north of Texas. Although the jungles of South America would seem similar to those of Africa, it is strange to find that none of the larger mammals are found in both places.

Palearctic and Nearctic Realms. The Palearctic realm includes all of Europe and Asia north of the Himalaya Mountains and a small strip of Northern Africa as well as Japan and Iceland. The Nearctic realm

includes North America north of Mexico and also Greenland. These two realms are mentioned together because they are very similar. The mammals include bears, deer, beavers, squirrels, wild cats, and foxes. The birds include finches, wrens, thrushes, ducks, and hawks which belong to the same or closely related species. The land bridge from Alaska to Siberia probably accounts for the similarity of the animal life in these two realms.

Animal Distribution in the Ocean

The sea is often called the cradle of life because all the phyla are represented there and several, particularly the Echinodermata, are restricted to marine habitats. The more primitive phyla are particularly abundant in the sea, and our fossil records indicate that for a long time all life was in the sea. There are three main types of marine habitats.
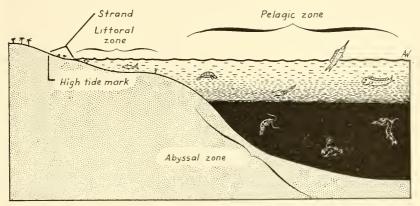
FIG. 29.3. The ocean zones.

The Littoral Zone. This region is the shallow sea, usually extending out as an underwater shelf from some great land mass. In general, its depth ranges up to about 600 feet. Light penetrates the water in this zone and there is a good growth of marine plants especially in the shallower portions of the littoral zone. Life is extremely abundant and varied. Every available niche is occupied, and animals are even found growing on one another. Because of the struggle for existence, every organism must be very well adapted in order to survive.

A very special area of this zone is known as the strand, which is the area that lies between the low and high tides. Here the animals are exposed to the drying effects of the sun's rays and the wind twice a day when the sea recedes. Here, also, they must be able to resist the pound-

ing surf. Animals, such as the barnacles, grow on the surfaces of rocks and close their shells tightly when necessary. Clams and many marine worms bury themselves in the sand and mud which remain moist until the tide comes back. Tides vary in height from one and one-half inches in the Mediterranean to over fifty feet in the Bay of Fundy.

The Pelagic Zone. This zone includes the open sea to the depth that light penetrates. Animals here must either swim or float, since there is no bottom on which to attach themselves or to rest. Among the larger animals we find the whales and porpoises. At the other extreme we find many very tiny animals, including those which are microscopic. These are often found floating together in great masses known as plankton. Many animals in this zone have special organs which keep them afloat. The Portugese man-o-war has a float filled with air which is so large that it serves as a sail. Many of the smaller pelagic animals achieve protection through transparency. Some are so transparent that one can see through them so perfectly that it is hard to realize that they are really present. Both the swimming and floating forms are similar in the Atlantic and the Pacific oceans.

The Abyssal Zone. This region occupies the ocean depths beyond the point of light penetration, including the floor of the ocean in these deep areas. According to William Beebe's observations in his bathysphere, no light penetrates beyond 1500 feet. The water is always very cold, and the pressure is tremendous; but, because this pressure is distributed throughout animals' bodies, it has little effect except when animals are brought up. When raised to the surface they usually swell up and the air bladders of bony fish may explode. No food is produced in this area, since without light there can be no photosynthesis. The ultimate source of all food is from the bodies of plants and animals which sink down from the light areas up near the surface. This includes everything from whales to the microscopic organisms, which sink gradually down through the miles of water like gentle rain.

Abyssal animals fall sharply into two groups, those that are scavengers, living on this shower of dead organic matter, and those that are predators on the scavengers or on each other. The most abundant deepsea animals are the sea cucumbers; others being snails, crustaceans, tunicates, cephalopods, and fish. The predaceous fish have large mouths filled with long, sharp teeth, and stomachs capable of great stretching, for they actually swallow other fish larger than themselves. Many of these have lures with a light on the end which attracts their prey, and many also have a row of lights on their bodies. Light-producing organs are also found in the coelenterates, echinoderms, annelids, crustaceans, and cephalopods. Many of the fish have large telescopic eyes. It is

believed that the lights which are found on many of these animals not only help in finding food and seeing what is about them in this total darkness, but they also help the animals find one another during the reproductive season.

REVIEW QUESTIONS

1. Explain why some species of animals reproduce very rapidly and become established when introduced into a new environment.

2. Why are birds generally more widely distributed than mammals?

3. Name several ways in which man aids animal distribution.

4. What are some of the ecological barriers to dispersal of animals?

5. How does sporadic migration differ from annual migration?

6. What are some of the factors which have caused a reduction in the range of certain animals?

7. Give examples of how man has brought about extinction of some species of animals.

8. How can relic survival explain the discontinuous range of many forms of animals?

9. List the geographic realms and the types of animals found in each.

10. Name the ecological zones of the oceans, and give the types of animals found in each.

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Ecology and Wild Life Conservation

The study of organisms in relationship to their environment is known as ecology. In recent years this subject has become very important in many fields that are of vital importance to man. The principles of ecology have been applied to agriculture, forestry, animal husbandry, wild life management, fisheries, and conservation of the land and water with amazing results. Many students of conservation believe that the fate of mankind rests on our ability to stop soil erosion before all our tillable land washes into the sea. A reliable report estimates that one third of our land is already hopelessly destroyed and another third is badly damaged and will soon be eroded beyond hope of recovery. That will leave us only one third of our tillable land to support our rapidly expanding population. When land becomes badly eroded, it not only becomes unproductive but the people living on it become poor, malnourished, and a social problem. Finally the valuable wild life dies or deserts the area.

In recent years county agents, soil conservation experts, and colleges of agriculture have combined their efforts in an attempt to reverse this trend which threatens to change us into a "have not" nation comparable to China and India with their starving millions. They have classified land according to its proper use for those who request it. They have recommended that hilly land be kept permanently in forests, land with moderate slopes be used for pasture but not plowed, and only the relatively flat lands be used for crops. These better lands have been further divided into those that require special care and those that do not. In the first group plowing should be done along the contours of the fields to reduce erosion, and a strip of soil-binding wheat or rye alternated with corn, potatoes, or similar crops which do not hold the soils properly. Terraces can make still steeper slopes available for crops. Gullies have been stopped by planting soil-binding plants or by a series of small dams. The most rugged lands have in many cases been turned into parks or public forests and planted with trees where necessary by federal, state, or local governments.

Succession

A mature biological community remains the same for a long time, unless the area is affected by some natural or human agency such as a fire, flood, or glacier. When the community is completely destroyed, one type of vegetation after another will appear in a regular series of steps which may require hundreds or even thousands of years. Eventually such a region will again reach a **climax** in development in which dominant species of trees and animals will take over the region. For example, after the continental glaciers melted in the northeastern states some 20,000 years ago, they left the landscape completely bare of soil and denuded of all life, both plant and animal. Many **seral stages,** one after the other, occurred in the region before the climax forest was restored. As the glaciers receded, animals such as the caribou, arctic hares, arctic foxes, and many birds migrated across the region carrying the seeds and spores of plants which started growing, and it was not long until some plant life was re-established. The first plants were species of lichens and mosses which require little soil, and the first animals were insects, the larvae of which feed on such low plants. As soon as a little soil had accumulated in low patches, fast-growing annuals became established. These were followed by perennial herbs and pioneer shrubs such as blackberries, dewberries, raspberries, blueberries and huckleberries. Ground nesting birds such as pipits, longspurs, and horned larks now found a suitable habitat along with some predatory mammals and birds. As the soil deepened, larger shrubs became common and tough, pioneer trees became established. Rabbits now found suitable cover, deer began to browse on the shrubs and small trees, a varied fauna of birds which nest in shrubbery became established, and the larger carnivores, such as foxes and wolves, followed. Next a growth of pioneer trees such as swamp maples, sassafras, persimmon, cedars, and pines began to crowd out the low vegetation, and squirrels, tree-nesting birds, wood-boring insects, and many other forms of animal life now found a suitable home. Birds and mammals of the open country were then crowded out or reduced to a few colonies in open spots. Finally, such slow-growing but dominant trees as sugar maple and beech, or white spruce farther north, gained a foothold and raised their crowns above the forest and gradually crowded out many of the smaller, short-lived trees. Rabbits no longer found their favorite brier patches, deer had to search elsewhere for tender twigs on which to browse, and birds of the shrubby habitats became scarce. However, as old trees developed dead branches and hollow trunks, more woodpeckers found food and homes, and more dens became available for raccoons,

squirrels and other den-loving species. After these seral stages (or sere), the forest finally became relatively static again and remained that way until our ancestors destroyed it once more with the ax and saw.

Another interesting succession occurs along the shores of a shallow lake as it gradually fills up with sediments and aquatic vegetation. This is illustrated by Reelfoot Lake in western Tennessee, a lake that was formed when an earthquake in 1811 caused the land to settle. In the century and a half since then, many parts of the shallow lake have filled up with aquatic plants and debris. A large patch of open water at the southern end of the lake contains many fish; diving birds, such as ducks, grebes and coots which swim on the surface, and a varied plankton furnishes an abundance of food. Water plants, such as pondweeds and water lilies, float on the surface of the shallower portions of the lake, many of them with their roots in the mud bottom. Here feed the cat-fish and turtles, herbivorous ducks dive for roots or tip-up for them, and aquatic insects are common. Closer to the shore or in very shallow places, plants with their roots in the muddy bottoms send their leaves and flowering stalks into the air. These include saw grass, cattails, and sweet flag. Here the bitterns and redwing blackbirds nest a few inches above the water, the kingrail piles up its mound-like nest on the bottom, the grebes construct their floating rafts, and the muskrats build their dens. Wading birds, such as herons and egrets, feed here on tadpoles, frogs, and water insects. Water snakes are most common in this zone. Cypress trees grow to large size in one area and play host to a great colony of nesting egrets and herons. A peregrine falcon also nests in a similar location. On the shores of the lake, where they may be occasionally flooded in wet seasons, grow many woody plants that need semi-aquatic conditions, including swamp maples, black willows, and button bush. Here may be found the raccoon and mink, and such nesting birds as the yellowthroat, waterthrush and prothonotary warbler, the latter particularly abundant in dead snags often standing in the water. Finally on the dry land beyond the influence of the lake, there grows the typical trees and shrubs of the region, inhabited by upland birds and mammals.

In recent years the aquatic plants have encroached so rapidly upon the open water of Reelfoot Lake that they threaten the very existence of the lake. The U. S. Fish and Wildlife Service now face the dilemma of either draining the lake and turning it back into farmlands which would displease the sportsmen, or dredging the shallow places and raising the water level to prevent the plants from coming back and thus displeasing the farmer, some of whose fields would occasionally be flooded.

Biomes

Since the types of vegetation control to a large extent the distribution of many species of animal life, we must classify the ecological habitats in terms of dominant plant associations, called **biomes**. Of course, animals do affect these plant formations in many ways. Caterpillars may destroy or at least severely damage many trees in an area and make room for smaller shrubs. The American buffalo is believed to have extended the grasslands biome by destroying the woody plants along its boundaries. Deer and elk will browse so severely on the bark of aspens and
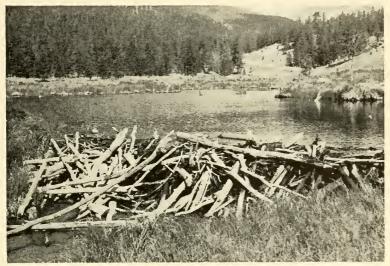
Photo by Winchester

FIG. 30.1. A beaver dam and the lake formed by it in the Rocky Mountain region of Colorado. These dams are of great ecological significance.

other trees during long cold winters that the trees will die and so open up the woods. Beaver will dam streams and form lakes in which sediments will accumulate year after year. In New York State hundreds of feet of such sediments have accumulated in some of the valleys creating a rich soil. Beavers also cut down the trees around their dams and form an opening in the forest which will bring in new species of birds and other animals. Birds also plant many species of plants by carrying the seeds in their digestive system and dropping them from some favorite perch. When a tree dies in the middle of a pasture birds will sing from its dead branches and there springs up beneath their perches blackberries, green briers, sassafras, dogwood, persimmon, red cedars, and other species producing highly colored, edible berries.

The term biome has been applied to the formation or association of plants and animals which cover a large area in which the climate and other conditions are fairly uniform. All the organisms which live in a biome are called the *biota*. In North America north of Mexico the two main factors in the distribution of plants and animals are temperature and rainfall. The following biomes are usually recognized: tundra, northern coniferous forests, the deciduous forests, southern evergreen forests, the great plains grasslands, deserts, western coniferous forests, and the tropical biome, the latter occurring only in the southern half of Florida.

The Tundra Biome. In northern Canada and the arctic islands, conditions are so frigid, the growing season is so short, the soils are usually so thin, and the winds are so strong that no trees can survive there. Typical plants are reindeer lichens, mosses, and fast growing annuals which spring up and bloom for a few days each summer. The reindeer lichen furnishes much of the food for arctic hares, the caribous, and larval stages of many arctic butterflies and other insects, and so indirectly for the arctic foxes and wolves that prey on them. Tundra plants grow under rather similar conditions on the highest mountains of New England and New York, and down the Rocky Mountains nearly to the Mexican border.

Northern Coniferous Biome. This has been called the spruce-moose formation after the largest animal and the dominant tree. This biome is characterized by cone trees of many species with needle-like foliage. Only one, the larch, sheds its needles in the winter. This formation extends across southern Canada and then enters the northeastern states and down the mountains as far as eastern Tennessee and western North Carolina. Timber wolves formerly preyed on the moose, and deer are fairly abundant. The ruffed grouse and the spruce grouse are typical game birds. Glacial lakes are very numerous and are filled with cold-water fish.

Deciduous Biome. This biome covers most of the eastern states as far west as the Ozarks of Missouri and Arkansas and as far south as the Gulf States. Dominant trees in the northern part of the area are sugar maple and beech, in the southern parts oaks and hickories are most abundant with the graceful tulip poplar common in rich bottomlands. The foothills of the southern Alleghenies have the greatest variety of trees of any region in the world. As the forests have been cut, the wild turkey has become scarce but the white-tailed deer has become increasingly abundant at least in the northern half of the region. Bobcats and foxes are the largest carnivores today; black bears are still common in the mountains. Tree-nesting birds are most abundant, but the bobwhite

is the typical upland game bird. Although the passenger pigeon has become extinct, its relative the mourning dove has remained fairly common due perhaps to its habit of nesting almost every month of the year. Amphibia, particularly the salamanders, reach their climax in the southern Allegheny Mountains. Glacial lakes filled with fish are common in the northern half of the biome.

Southern Evergreen Biome. From coastal Virginia around the Gulf Coast to eastern Texas grow long-leaved pine mingled with such broadleaved evergreens as magnolia, live oaks, and many evergreen shrubs.

Photo by Lovell

FIG. 30.2. The "elk line" in an aspen grove in the Rocky Mountain National Park. These aspens are in danger of dying because too much of their bark has been eaten by elk during the winter. Such overpopulation is due to the absence of large predators, such as mountain lions, which normally keep the elk in balance with the available food supply.

The cabbage palm and scrub palmettos give the area a subtropical appearance. Along the coast the trees are festooned with Spanish moss, a gray moss-like plant belonging to the pineapple family. The pine lands are maintained by burning and probably represent only a subclimax. The largest animal is the alligator. The eastern diamondback rattlesnake and the cotton-mouth water moccasin abound along with the beautiful coral snake. Lizards and turtles also are common throughout the region. Sea birds nest along the coastal islands of the

Atlantic Ocean in great numbers, and great flocks of ducks and geese winter along the coastal marshes of Louisiana.

Grasslands Biome. The great plains extend from central Texas north into Canada. This region is characterized by light annual rainfall and rapid evaporation, conditions which are not favorable to the growth of large trees. In many parts of Wyoming or western Kansas one can look for miles in all directions without seeing a tree. Sagebrush and cacti are dominant plants in many areas. Grasses grow in bunches in the drier areas with bare spaces in between. Formerly the principal animal was the American buffalo, whose place today has been taken by

Photo by Winchester

FIG. 30.3. The bison or American buffalo. This great bull watches over a herd in Yellowstone Park, a small remnant of the great herds that once roamed our midwestern plains. The bison probably had much to do with extending our plains region because of their grazing habits.

cattle and sheep. The most interesting large mammal is now the antelope, and the coyote is the chief carnivore. The sage grouse and the prairie chicken are typical game birds.

Desert Biome. Portions of California, Nevada, Arizona, and west Texas are characteristic of the desert region where cacti, yuccas, Joshua tree, creosote bush, and other typical, dry country species grow. The saguaro cactus or giant cactus is the chief species but its range is limited. Many southern species of animals penetrate the United States only in this region. Snakes and lizards including the Gila monster are especially common. A long-tailed running bird, the road runner, preys on the snakes. The cacti are the home of many species of birds, such as the cactus wren.

Western Coniferous Biome. This forest extends from Alaska to Mexico. The portion in the Rocky Mountains differs considerably from that along the Pacific Coast, and they are often considered two regions. The dominant trees are western yellow pine, Douglas fir, and several other species of conifers in different regions and at different elevations. This is a region of many large mammals such as the elk, Rocky Mountain sheep, goats, and the grizzly bear. The birds and small mammals belong to quite different species than those in the eastern mountains.

Tropical Biome. In southern Florida occurs an extensive tropical flora that is Caribbean in origin. The area is relatively free of frosts, and most of the vegetation is evergreen. Many native species of palms abound, including the beautiful royal palm, and nearly all the palms in the world have been introduced. The crocodile occurs in the everglades, and the sea cow also lives here. A tiny race of deer still survive on the Florida keys. Great nesting colonies of egrets, ibises, herons, spoonbills and other tropical birds make the everglades a never-to-be-forgotten sight. Among the air plants growing in these moist surroundings are many species of orchids. Abundant marine life occurs along both coasts of Florida, and sponge fishing is an important occupation.

The Web of Life

> *"Big fleas have little fleas upon their backs to bite em,*
> *And little fleas have lesser fleas, and so, ad infinitum."*

The largest animals, such as the wolf and the cougar, prey on smaller animals; the hawk and owl prey on small birds and rodents; the mink and weasel prey on small rodents or fish; the shrew and the mole feed on insects and worms; many insects prey on other insects, and aquatic insect larvae feed on various organisms in the water; large fish feed on smaller fish and smaller fish feed on water fleas; water fleas feed on protozoa and bacteria. Eventually all food chains of predatory animals end in some herbivorous animals. When the large animals die, they are eaten by worms, insects, and vultures or destroyed by bacteria, and so they too become part of a food chain in the web of life. Many food chains lead to man. In a pond, protozoa eat bacteria and are in turn eaten by water fleas which are eaten by smaller fish which are eaten by bass; finally man catches and eats the bass and that chain ends. Some chains are even longer, whereas others are much shorter as, for example, a rabbit eats clover and man shoots the rabbit for his dinner. Small animals such as mosquitoes, bedbugs, lice, and ticks suck the blood from larger animals, including man himself. Even insects are often covered with

tiny mites, and protozoan parasites infest even the tiniest of many celled organisms; even hydra has a species of ciliated protozoan which clings to its body apparently living off its secretions. The old verse had more than a spark of truth in it.

Photo by Lovell

Fig. 30.4. Cowbird eggs in the nest of a wood thrush. Here, eight spotted cowbird eggs have replaced all but two of the eggs of the wood thrush. This parasitism probably arose because the cowbird followed bison herds and did not stay in one place long enough to nest like other birds.

The Balance of Nature

One of the most important concepts that has been developed by ecologists is the balance of nature. A common question asked by the biological illiterate is: "What good is that predator or that parasite?" Perhaps they help keep some species of fast-reproducing animal in check and so prevent it from occupying more than a fair share of the earth's surface. The American Indian lived with nature, took only what he needed, and rarely upset the natural conditions. Modern man, however, has upset this balance in nearly every part of the world. Modern civilization destroys not only the animals and plants but their habitats as well, often with disastrous results to wild life and to man himself. Great floods have inundated our cities since the protective cover of the forests has been removed. The giant reservoirs created by hydroelectric dams are rapidly filling up with silt because irresponsible farming

and grazing on the surrounding hills allow erosion to proceed at a rapid rate. Excessive draining of swamps and small ponds has destroyed the nesting ground of ducks and geese and spoiled the recreation for many hunters. The pollution of our streams with sewage and factory wastes has turned many of them into aquatic deserts with hardly any organism surviving and certainly not game fish. Excessive hunting and other factors have either exterminated or greatly reduced the numbers of our wild game, and at the present time thirty species of mammals and fifteen of birds are believed in danger of extinction. Most of our 375 million acres of primeval forest have been slashed and chopped to the ground and further injured by careless fires and excessive grazing.

As early as 1818 the people of Massachusetts recognized the decline of wild life and placed a closed season on snipe; and in 1821 New Hampshire protected beaver, mink, and otter by a closed season. The first state game wardens are said to have been appointed in Michigan and Wisconsin in 1887. By 1890 nearly all states had some kind of game laws, but they were very poorly enforced. The wearing of stuffed birds on hats became very popular about the turn of the century, and songbirds were slaughtered in vast numbers to supply the millinery trade. The plumes from the heads of breeding egrets also became very popular. Since these plumes were best developed during the breeding season, the birds were slaughtered on their nests leaving the nestlings to die. This created strong resentment not only among nature lovers, but among all those with humane instincts. A national appeal to women led many groups of women to pledge themselves not to wear stuffed birds or plumes on their hats, but the free advertising is said to have doubled the sale of the product. The Audubon Society established a refuge for nesting colonies of the egrets in Florida, and two of their wardens were killed by the plume hunters. However, protection continued with excellent results. In North Carolina the State Audubon Society was incorporated in 1903 as the game enforcement department. Fees for hunting licenses went to them, and they hired the wardens. The State Audubon Societies were particularly active in many states in the first few years of the present century and helped to pass state laws to protect songbirds which were still being eaten in large numbers.

The federal government came to the aid of the states in 1900 by passing an act which prohibited the sale of "bootleg" game in interstate commerce. However, it was not until the United States signed a treaty with Canada in 1916 to protect migratory game, insectivorous, and other migratory nongame birds that the federal government lent real aid in this field. With federal wardens aiding state wardens, the restoration of many kinds of wild life proceeded very successfully. The very im-

portant Pittman-Robertson Act was passed which placed a 10 per cent excise tax on guns and ammunition, the money to go to the states to carry on research in restoring and improving game and other wild life. The state has to add 25 per cent to qualify for this fund. In 1950 the Dingell Act provided a similar fund by a tax on fishing equipment for the study and restoration of fish and aquatic habitats.

Restoring Wild Life

It became possible to put into practice the principles of ecology to restore wild life only when there were effective laws to protect it from irresponsible hunters. For example, Pennsylvania became the first state to develop a system of state game refuges. At that time beaver had been exterminated in that part of the country. A few were trapped farther north and introduced into some of the refuges. They multiplied under protection and soon became so abundant in these preserves that a limited trapping season was tried in the surrounding country. As only the surplus was taken, the beaver continued to increase and prosper, and now trapping beaver is again a lucrative occupation in the state of Pennsylvania. This led to the realization that surplus wild life could be harvested like any other crop without reducing it in numbers. As early as 1878 the native deer were all killed off in southern Vermont and were rare even in the northern part of the state. An efficient system of game wardens in recent years has given the survivors much needed protection. The cutover land has been allowed to grow up, and hundreds of unproductive farms have been abandoned and they too have become overgrown with pioneer shrubs and trees, furnishing ideal conditions for deer to browse. Recently the deer herd was conservatively estimated at 60,-000 head; and, in spite of increasing pressure by an army of hunters each fall, the deer remain so abundant that they sometimes damage orchards and forest lands in the long cold winters. Only the surplus are being harvested.

One of the most difficult problems has been the attempt to save the ducks, geese, and swans. After World War I, the improvement of roads, the increase in motor cars, and the great increase in trained hunters reduced the population of many species of waterfowl to a danger point. It was estimated by 1934 that, as compared with 1900, only 10 per cent of the water birds of North America had survived. The situation was further aggravated by a series of dry summers which dried up the water holes; and, to make work for the army of the unemployed, many marshes useful to waterfowl were drained. The Biological Survey, a federal agency entrusted with the problem, began to put back the water holes in

the north central states. Spring hunting was abolished and the fall season was greatly shortened, the bag limit was drastically reduced, and other restrictions were placed on hunting. Federal refuges from Canada to the Gulf Coast were developed to furnish food and safety for migrating birds in order to save enough for breeding stock the following spring. Hundreds of acres of wild life food plants were planted around artificial ponds on the refuges and soon millions of ducks and geese were finding protection there. A group of private individuals raised millions of dollars to improve the nesting sites of waterfowl in Canada where the majority of the birds nest and raise their young. As a result of all these efforts, there has been a moderate increase in the population of ducks and geese, but the permanent loss of proper habitat due to the growing human population makes further increase doubtful.

The Role of the Predator

A large number of animals (mammals, birds, reptiles, amphibians, and fish) are carnivorous; that is, they eat the flesh of other animals. When they kill animals that are of value to man, it has been customary to regard them as obnoxious predators which should be destroyed. Stories of the "sly fox" or the "big, bad wolf" are present in many nursery tales and inculcate a hatred of such animals in young children. Modern ecologists have proved this view erroneous and have shown that predators have an important role in maintaining the balance of nature. If all the hawks and owls are destroyed, rodents become a serious pest. This actually happened in parts of Pennsylvania some years ago, where a bounty was paid on these birds. Rats and mice became so abundant when their natural checks were removed that farm crops were badly damaged. A pair of barn owls nesting in a barn have been estimated to save the lucky farmer twenty-five dollars worth of grain a year. Similarly a pair of red-shoulder hawks (better known as mouse hawks) nesting in his wood lot and patrolling his meadows and farm lands all day may be worth the same amount. Even the fierce Cooper's hawk, often known as the chicken hawk, may actually serve an important function in keeping wild life healthy. Such gregarious upland game birds as the quail are often attacked by contagious diseases which may spread rapidly through the whole covy. However, when a Cooper's hawk swoops down on the covy, the sick bird will be too slow to escape and will be caught and devoured by the hawk before the disease has had time to spread; the hawk will also remove birds with hereditary weaknesses. For these reasons predators are often spoken of as the doctors of the wild who not only prevent the spreading of a disease but also

remove defective birds before they can pass these defects on to their offspring.

In the same way foxes, wolves, lynxes, and cougars may be beneficial to wild life. Rabbits often catch a disease known as rabbit fever or tularemia. Unfortunately, man may catch this often fatal disease by cleaning one of these rabbits. If foxes are present in the area, they will be able to run down these diseased rabbits and kill them before the disease is spread to other rabbits. In a national park in Canada it is the policy of the management to maintain a small pack of wolves to keep the deer healthy and under control. In the Kaibab Refuge in Arizona

Photo by Lovell

FIG. 30.5. Cooper's hawk is a predator which keeps many small animals alert and healthy by killing the sick and physically handicapped. This hawk also prevents overpopulation of many small birds and mammals.

some thirty years ago, the mule deer became so numerous that they overgrazed and overbrowsed the forest land killing many of the young trees and causing severe erosion. At that time wild life ecologists had not discovered that large game may become too abundant for the carrying capacity of the land. Since large carnivores such as the cougar and the wolf had been exterminated, there were no predators to keep the great herd healthy and in bounds. As a result of starvation and disease, a considerable portion of the herd perished; but, even worse, the carrying capacity of the land was permanently damaged so that the area will now support less deer than before. When the wild life technicians discovered it was necessary to kill off the surplus, there were so many protests that it took a Supreme Court decision to settle the point that

the federal government has the right to do this. Local courts ruled that only federal wardens could be used to kill this excess, not hunters.

Farm Habitats

With so much of our country under cultivation or in pastures, the only hope of increasing our wild life, according to game technicians, is for the farmer to consider it an additional crop. However, the practice on many modern farms is to remove all the brush from their fence rows, stream banks, and odd corners—the "clean farming" policy. This leaves no cover for rabbits, no browse for deer, and no nesting sites for quail and insectivorous birds. To bring back the game, wild life experts are recommending that natural fence rows be made by planting multiflora rose. This remarkable plant grows so rapidly that it will turn a ·cow in three years and a pig in five, and it will last for many years without cost to the farmer. This hedge not only furnishes nesting sites and cover but also an abundance of rose fruits (called hips). The farmer is further urged to keep cattle out of his wood lot to improve both the timber and the wild life habitat. When erosion is a problem, he is urged to plant such shrubby plants as bicolor lespedeza, coralberry, indigo plant, and Siberian pea-tree which will furnish wild life foods as well as control erosion. In many states the division of Fish and Game or Conservation will furnish the farmer these plants either free or for a very small cost.

Another important habitat is the farm pond which can have many uses other than watering stock if properly constructed. An acre of farm pond will furnish eight to ten times as many pounds of fish as an acre of land will furnish in pounds of beef if the water is fertilized regularly with a balanced fertilizer. If the pond is stocked at the farmer's expense, he can seine it from time to time, store as many pounds of fish as he has need for in his deep freeze, and throw back a few of the large fish for breeders and the small fish for greater growth. He can maintain a proper ratio of rough fish to food fish. If he prefers, he can use the pond for recreation and catch the fish on rod and reel. Such ponds can now be built in a day or two with a bulldozer, but they should be carefully fenced against cattle who usually ruin them in a few years by trampling their banks and polluting the water. These ponds are a great boon to wild life which will increase in any area where water was scarce.

Overgrazing is another bad practice which hurts both the owner and the wild life. A recent study in Arizona has shown that this will destroy the valuable perennial grasses and allow cholla cactus,

prickly pear, and several other useless thorny plants to increase. Undesirable rodents, such as kangaroo rats, prairie dogs, ground squirrels, and wood rats, increase in abundance under these conditions; but deer, antelope, and sage grouse become scarce. On the other hand, if grazing cattle are reduced to a point where the valuable perennial grasses can survive, the cattleman not only harvests better beef; but the undesirable rodents are reduced in number and more valuable wild life returns.

The practice of burning pasture land and wood lots in many states also has undesirable results. The burning destroys valuable humus as well as removing the cover so necessary for survival of valuable game and insectivorous birds. Pernicious weeds take over and become more abundant when the land is burned often. The only bird which becomes more common is the crow, which in large flocks may become an annoying pest. Hawks and foxes easily catch most of the game which has no place to hide, and prairie dogs, ground hogs, and other rodents take over. Every time a farmer burns off a crop of weeds rather than turning them under with the plow, he has destroyed many dollars' worth of fertilizer per acre.

To summarize, we have found that the ecologist has learned principles that are of vital importance to man if he is to conserve his natural resources. The web of life is very complex, and the balance of nature can be maintained only by preserving all sorts of animals including the predators. When man upsets this balance, the results may be disastrous not only to wild life but to human health and society. In recent years the wild life ecologist has restored both small and big game far beyond the hopes of the most ardent conservationist. One of the most important problems today is to educate the farmer and the stockman to recognize that wise practices will benefit both them and wild life.

REVIEW QUESTIONS

1. Define ecology.
2. What are some fields where ecological principles have been applied?
3. What are some methods of preventing erosion on sloping land?
4. Describe steps by which a bare ledge becomes a rich forest and compare with the changes from a shallow lake to a forest.
5. Describe the biome in which you live.
6. Trace the food chains for the kinds of flesh you have eaten in the past month so far as is possible.
7. How does man upset the balance of nature?
8. Trace the development of game laws for the protection of wild life.
9. How have the Pittman-Robertson Act and the Dingell Act increased your possibilities for recreation?
10. What is meant by harvesting the surplus of wild life? Explain how it works on beaver and deer.

11. Why has the restoration of the waterfowl population proved to be a nearly impossible task?

12. Why do most people have such a bad opinion of predators?

13. Why are hawks and owls considered to be useful to the farmer?

14. Explain why predators are called the doctors of the wild.

15. How do Canadian parks keep their herds of deer healthy and in balance with the food supply?

16. Explain the factors leading to the catastrophe on the Kaibab Reservation.

17. How can farmers improve wild life habitat?

18. Why is burning over land so detrimental to wild life?

19. Describe the operation of a farm pond for food fish.

20. What is the importance of a chain of migratory bird refuges?

31

The Bridge of Life

Between one generation of animals and the next there exists a tiny protoplasmic bridge over which all of the inherited characteristics must be passed. The tiny sperm of the male and the somewhat larger egg of the female must contain the factors that account for all of the inherited characteristics that pass through the generations. It is no matter of chance or environment that causes a female cat to give birth to kittens rather than puppies or a hen's egg to hatch into baby chicks rather than ducklings. There are genes within the reproductive cells from which these animals are derived that cause them to develop into something quite like their parents. Yet, this similarity is never complete. Human children are never exact duplicates of their parents— they show some characteristics found in one parent, some found in the other, some which are intermediate between the two, and some that are shown by neither parent. Children of the same parents will also show differences among themselves, yet they will be more alike than first cousins. First cousins, on the other hand, will show greater similarities than nonrelated children of the same race, and children of the same race will be more alike than children of different races. To go a step further, children of different races certainly resemble one another more than the offspring of different species of animals. These are commonly observed facts which have their basis in the similarities and differences of genes among these forms of life of differing relationships. It will be our purpose in this chapter to learn how these genes bridge the gap from one generation to the next. We will begin with some of the early speculations on this interesting subject of genetics in order that we may see how science has replaced pure speculation and superstition with verifiable facts.

Early Speculations on Heredity

The famous Greek philosopher, **Aristotle,** who lived several hundred years before the time of Christ, gives us one of the earliest recorded theories of heredity. He suggested that the semen of a man was produced from his blood; in fact, he thought of it as highly purified blood

which possessed the ability to give form to a new human life. A woman's menstrual fluid was supposed to be the female semen, but she did not have the power to achieve the same high degree of purification characteristic of man. When these two fluids combined, as he assumed they did during intercourse, the semen of the man was supposed to give form to the embryo, while that of the woman was supposed to furnish the substance from which the embryo was formed.

From *Genetics*, Winchester, Houghton Mifflin

FIG. 31.1. Preformation. Some men of the seventeenth century imagined that they could see miniature human embryos within human sperms. These are drawings after Hartsoeker, 1694, on the left, and after Dalempatius, 1699, on the right.

Other great thinkers of the ancient Greeks added to this the thought that the semen from both man and woman originated from the body parts which they were to form. In other words, the hands of a man would produce semen which would migrate to the reproductive organs where it would mingle with semen produced by the other body parts. When introduced into the body of a woman, it would stimulate the formation of hands in the embryo which would resemble those of the person from which the semen originated. Through this supposed

blending of semen from different body parts of both parents, inheritance was accounted for.

It was not until the microscope was discovered during the latter part of the seventeenth century that a truer picture of heredity became apparent. **Anton van Leeuwenhoek,** a Dutch lens maker, mentioned in Chapter 2 in connection with the discovery of the cell, gets credit for being the first to observe human sperms. He used crude, yet efficient microscopes of his own making. When he saw these tiny, wiggling organisms in human semen, he suggested that each of these "animal-cules," as he called them, was a potential human being and that any one of them could develop into such if introduced into the womb of a woman where it could be nourished. This theory failed to explain how characteristics could be inherited from the mother, but it did represent a great milestone in the discovery of the true physical basis of heredity. Some scientists of the time even imagined that they could see tiny human beings within the head of the sperms and made drawings to show such (see Fig. 31.1).

Another Dutch scientist, **Regnier de Graaf,** helped complete the picture when he observed the similarity between the ovaries of women and those of birds. He concluded that women produce eggs similar to those of birds, but much smaller in size, and that these eggs unite with sperms to produce human embryos. The egg with the cells surrounding it has ever since been called the Graafian follicle.

A Frenchman, **Jean Baptiste Lamarck,** came forth with an intriguing theory which was widely discussed during the first decade of the nine-teenth century. His theory held that the reproductive cells were in some way influenced by the bodies of the parents so that the cells transmitted these new characteristics which were acquired to their offspring. A giraffe was supposed to have a long neck because it continually stretched it in an effort to reach leaves on high trees, and this stimulated the growth of the bones, muscles, blood vessels and other structures in the neck region. Each generation's stretching was passed on to the offspring, and the necks of giraffes have become longer and longer from one generation to the next. This supposed inheritance of the effects of use or disuse of a body part is called the theory of the **inheritance of acquired characters.**

The famous English scientist, **Charles Darwin,** came into the picture during the middle of the nineteenth century. He proposed a mechanism by means of which such acquired characteristics could be transferred to the offspring. He assumed that tiny bodies, he called them **pangenes,** were formed in the various body parts and migrated to the reproductive cells. For instance, if a blacksmith used his arms extensively and the

muscles of his arms became highly developed, then the pangenes formed in these muscles would migrate and become a part of his sperms. If this blacksmith then had a child, this child would have strong arms because of these pangenes.

It remained for a German, **August Weismann,** to disprove these various theories on the inheritance of acquired characteristics. He cut the tails off a group of new-born mice and when they reproduced, the tails were cut from the offspring and so on for twenty generations. When the twenty-first generation appeared the tails were allowed to grow and these had tails just as long as other mice that did not have

From *Genetics*, Winchester, Houghton Mifflin
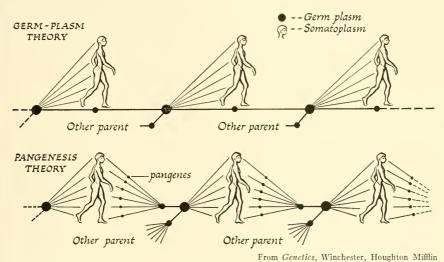
FIG. 31.2.   Weismann's germ-plasm theory contrasted with Darwin's pangenesis theory.

a history of tail-clipping in their ancestry.   From this and other studies he concluded that the reproductive cells were carried by animals, but were not influenced by the activities of these carriers.   He spoke of the cells directly involved in reproduction as the **germ plasm** and the rest of the body as the **somatoplasm.**   He maintained that the germ plasm formed a continuous stream from generation to generation producing the somatoplasm, but not being altered by it.   Fig. 31.2 shows the distinctions between the pangenesis theory of Darwin and the germ-plasm theory of Weismann.   The accumulating evidence from many sources has led geneticists to accept Weismann's viewpoint that the germ plasm is not influenced by the somatoplasm—in other words, that there is no inheritance of acquired characteristics.   A person can transmit to his offspring only those genes which he received from his parents.   We do

know that genes may change at rare intervals through mutation and thus something new may appear, but mutations are random things which bear no relation to the activities of the organism carrying the genes.

We could not close a historical account of the development of the science of genetics without mentioning the one man who did more than any other to start modern research in the field of heredity. This man was **Gregor Mendel,** a monk who lived in a monastery in Brunn in central Europe during the latter half of the nineteenth century. Through an extensive series of breeding experiments with garden peas, Mendel worked out the method of gene transmission which we now know applies to most forms of life.

With this background on the development of thinking on the physical mechanism of heredity we can now turn our attention to a more detailed study of the bridge of heredity.

Meiosis

In Chapter 2 the method of cell duplication through mitosis was described in some detail. In that chapter it was pointed out that a special type of mitosis, known as meiosis, was necessary when gametes were produced or there would be a doubling of the chromosome number each generation when sperms and eggs united. We will now consider this process of meiosis more fully and learn how it is connected with the mechanism of heredity. It will be well to review Chapter 2 carefully before proceding with this study, because a thorough knowledge of mitosis is necessary for an understanding of meiosis.

It should be kept in mind that the primary accomplishment of meiosis is the production of cells with only one half of the chromosome number which is normally found in the body cells. This is done by a series of two cell divisions. The process is essentially the same for all animals, but let us take man as a specific example. Man has 48 chromosomes in his body cells. These are of assorted sizes and shapes, but it can be noted under the microscope that there are two of each kind. In other words, each chromosome will have a homologous mate like itself in size and shape which contains similar genes. (In the male there is one exception to this—one pair of chromosomes are somewhat dissimilar. This pair is connected with sex determination.)

In the **prophase** of ordinary mitosis, each of these chromosomes becomes doubled; then they line up at the metaphase plate and are pulled apart so that a full 48 chromosomes goes to each of the daughter cells which is formed. In meiosis, on the other hand, there exists some at-

traction between homologous chromosomes so that they come together and form 24 pairs. Each chromosome becomes duplicated as in ordinary mitosis, however, so each of the 24 pairs consists of four chromatids, but with only two centromeres. These tetrads line up at the **metaphase,** but there is no duplication of centromeres as in ordinary mitosis. The paired chromosomes are then pulled apart in the **anaphase,** and each daughter cell receives 24 chromosomes.
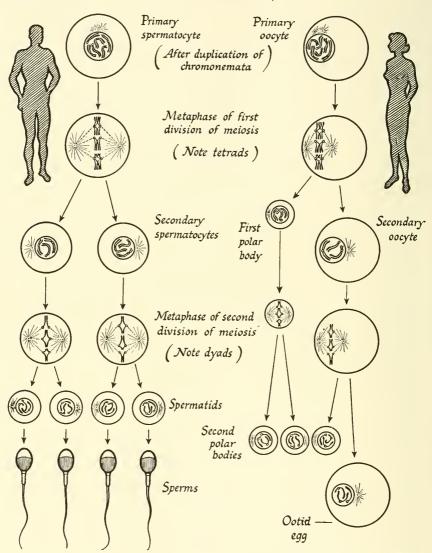
Meiosis is not yet complete, however, for each of these is a double chromosome (dyad) with two chromatids. Another prophase follows without any further duplication of chromatids, and the chromosomes line up at the metaphase spindle with two chromatids and one centromere for each chromosome as in ordinary mitosis. At this metaphase the centromeres become duplicated and the chromatids are pulled apart to form 24 single chromosomes for each daughter cell that is formed. Thus, in two cell divisions the number of chromosomes and the number of genes are reduced to one half. Gametes are then formed from these cells.

Spermatogenesis

This is the term used to refer to sperm production. Since there is some difference in the way in which meiosis occurs in the male and female, we will consider the two separately. A cell of the testes which is preparing to undergo meiosis is known as a **primary spermatocyte.** The first division of meiosis results in two **secondary spermatocytes** of equal size. These both undergo the second division of meiosis and produce four **spermatids.** Each of these is then converted into a **sperm** by an elimination of most of the cytoplasm, the concentration of the genes into a head and the development of a tail for locomotion.

Every male animal produces enormous numbers of sperms. Any one sperm has little chance of fertilizing an egg, and there must be enough of them to insure their presence at the proper place at the proper time. There will be enough sperms released by a man at a single ejaculation to fertilize every woman on this hemisphere of the earth if every single one were used. Thus, it is evident that the sperms are quite small, but they contain all that is needed. They contain the important genes concentrated in the head, a little stored food in a neck, and a long whip-like tail for locomotion. In spite of their small size, however, we should bear in mind that they contain just as many genes as there are in the female egg which is hundreds of times larger. Thus, each child inherits equally from father and mother, because the genes are the units of heredity.

SPERMATOGENESIS — (IN ANIMALS) — OOGENESIS

Primary spermatocyte / Primary oocyte
(After duplication of chromonemata)

Metaphase of first division of meiosis
(Note tetrads)

Secondary spermatocytes

First polar body

Secondary oocyte

Metaphase of second division of meiosis
(Note dyads)

Spermatids

Second polar bodies

Sperms

Ootid — egg
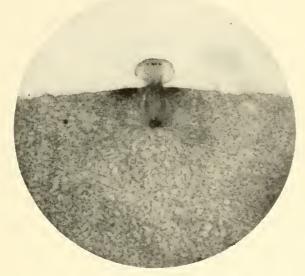
FIG. 31.3. Spermatogenesis and Oogenesis. These diagrams show the similarities and differences in the formation of sperms and eggs. For clarity of detail only six chromosomes are shown, although the human diploid number is actually 48.

Oogenesis

Oogenesis means egg production. A cell of the ovary which is preparing to undergo meiosis is known as a **primary oocyte.** The first division of meiosis in this cell differs from that of the primary spermatocyte in that the spindle figure is not across the center of the cell, but near one edge. When the two groups of chromosomes have separated, one group of chromosomes is included in a small cell which is formed at the edge of the larger cell. The small cell is known as the

FIG. 31.4. Unequal cell division in oogenesis of the whitefish. The polar body is being pinched off from the much larger oocyte, yet it receives the same number of chromosomes.

first polar body, and the large cell becomes the **secondary oocyte.** The second division of meiosis is also unequal, and a large **ootid** and a **second polar body** are formed. The first polar body usually divides again also so we end up with three small polar bodies and one ootid. The ootid then forms the **egg,** and the polar bodies disintegrate.

The advantage of this unusual type of division becomes apparent when we consider the functions of the egg. The egg must store food for the developing embryo and, therefore, must be larger than the sperms which need only enough food for energy to swim to the egg. By these unequal divisions there is one final cell which is much larger
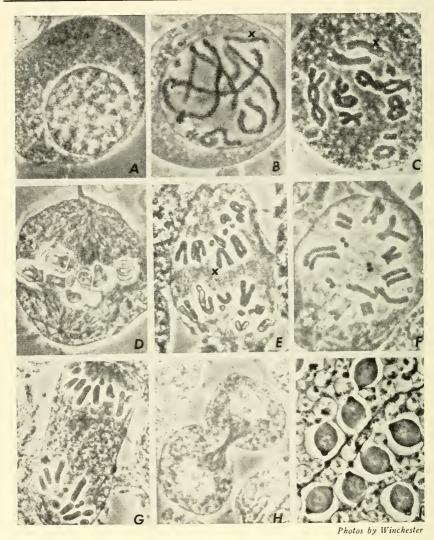
Fig. 31.5. Spermatogenesis as seen in living grasshopper cells from the testes. A primary spermatocyte (A) is preparing to undergo meiosis. In the early prophase of the first division of meiosis (B) the slender chromosomes can be seen after they have paired. The diploid number of this grasshopper is 23; thus there are eleven pairs and one unpaired (X-chromosome). In a latter prophase (C) it can be seen that each chromosome is double; thus there are four chromatids to each pair. Crossing over between chromatids of the paired chromosomes is evident. The X-chromosome at the upper part of the cell is unpaired and, therefore, shows no crossing over. In the metaphase (D) the chromosomes are greatly shortened as they line up in the center of the spindle. In the anaphase (E) the chromosomes have pulled apart. The chromatids have separated from one another everywhere except at the centromere end. This gives a V-shape to the chromosomes. Note the eleven chromosomes in the lower

than it would be if the divisions had been equal. Of course, only one of the four cells can become an egg, but this is no disadvantage because the number of eggs produced is small in comparison with the number of sperms. In a woman, for instance, there will be only about 350 eggs released from her ovaries during her entire lifetime. Each of these eggs has a much greater chance of being fertilized than a sperm has of fertilizing an egg, so the smaller number of eggs is sufficient. Even in those animals where the number of eggs produced by the females is very large the males still produce millions of times as many sperms.
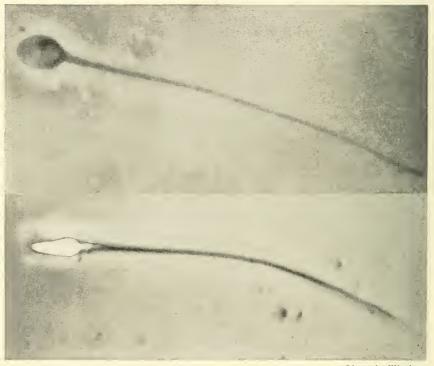
Fertilization

Now that we have learned how the gametes are produced we will turn our attention to the method by means of which the sperms and eggs come together to form zygotes which will grow into new individuals. In many water animals this problem is solved simply—the eggs and sperms are released in the water and the sperms swim to the eggs and fertilize them. In land animals, however, there must be a method of transferring the sperms directly to the bodies of the females by the males by the process known as copulation. Plants, with their restricted motility, have developed pollen grains which can be carried by the wind or insects and thus bring the male gamete to the female gamete, but such a method is not found among animals. Whether released in the water or in the body of the female, however, the sperms still must travel under their own power in the final stages of the journey to the eggs.

The meeting of the egg and sperm is believed to be due to chance. When millions of sperms are deposited near an egg, they swim in all directions, and some are certain to come into contact with it almost immediately. In a short time they form a thick mass, each sperm with its head pointed inward as if it is trying to penetrate the membrane surrounding the egg. The egg is known to contain a substance which causes the sperms to stick to its surface—they are trapped. It was formerly believed that the egg secreted a chemical which diffused through the water and caused the sperms to swim directly to it, but recent studies have failed to confirm this theory.

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group and the twelve, including the X-chromosome, in the upper group. In the prophase of the second division of meiosis (F) the double nature of the chromosomes is very evident as the chromatids are clearly separated. In the anaphase (G) the chromatids have pulled apart and now form separate chromosomes which appear as single rods. In the telophase (H) the secondary spermatocyte has almost completed division into two spermatids. Finally, the spermatids (I) are shown undergoing transformation into sperms.

Under normal conditions only one sperm enters the egg. One sperm is needed to restore the normal number of chromosomes for the body cells, whereas more than one would completely upset the chromosome balance. As soon as one sperm comes in close contact with the surface of the egg, something happens which repels other sperms. Some chain reaction must travel over the surface of the egg which causes it to reject all other sperms which may chance to come in contact with

FIG. 31.6. Living human sperms. The upper photomicrograph shows a flat view of the head, and a side view of the head is shown in the lower photomicrograph. These pictures were made with a phase contrast microscope. The sperms as they appear in this cut are enlarged about 2,000 diameters.

it, and those already held there are now released from the trap. It must be a very rapid reaction, or else two or more sperms would establish intimate contact and start to enter the egg before the repulsion was complete.

In the next phase of fertilization the egg bulges out at the point where the sperm is in contact with it and forms what is known as a **fertilization cone**. The sperm head becomes embedded in this cone,

and it appears as if the cone actually pulls the sperm head and middle piece into the egg leaving the tail behind. Meanwhile, the egg has formed a **fertilization membrane** around itself, within which the early stages of embryonic development will take place. This sperm head which, as we have already indicated, consists almost entirely of genes, then migrates inward to fuse with the nucleus of the egg and the gene number and chromosome number are restored to the original figure that existed before meiosis.
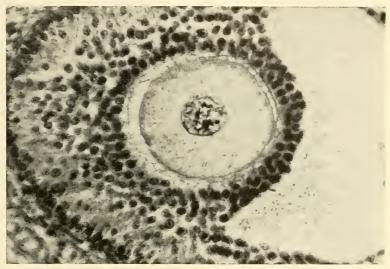
Photo by Winchester

FIG. 31.7. Human egg with its surrounding mass of follicle cells. This egg is shown within a follicle of the ovary. This cut represents about a 250-diameter enlargement.

When a sperm fertilizes an egg it brings genes in from the male parent and provides biparental inheritance, with the resulting variety among the offspring that would not be possible with a single parent. It performs another function, however, which is equally important—it provides the stimulus which is necessary to set in motion the events leading to mitosis and the development of an embryo. Profound physiological changes take place within the egg when the sperm head contacts it in addition to the physical changes which we have just described. For one thing, there is a tremendous increase in the rate of oxygen consumption—it will rise to about five times what it was before. This provides the energy necessary for the early stages of embryonic development. Also, there will be an increase in the permeability of the cell membrane. This would allow a more rapid exchange of substances

through the cell membrane and would be correlated with the higher rate of metabolism within the cell. Careful studies also show that the protoplasm of the egg increases in viscosity—it becomes more solid— along with these other changes and this is apparently necessary for cell duplication. Without these vital changes in the eggs there would be no embryo even though the sperm head should enter with its load of chromosomes.

It is possible to achieve an artificial stimulation of the egg which causes it to undergo the physiological reactions which normally come only with fertilization and in some cases an embryo may even develop.

Courtesy of Gregory Pincus

FIG. 31.8. A rabbit without a father. The little female bunny on the left, shown with its mother, was produced from an unfertilized egg. The egg was artifically induced to begin division without the entrance of a sperm. This shows that the egg contains all the genes necessary for the production of an individual, but normally will not do so without union with a sperm.

We have already learned that within the egg of most forms of animal life there are sufficient chromosomes and genes to form a complete individual. Normally, there will be two of each kind of chromosome in the body cells, yet one of each kind is all that is absolutely necessary. In some animals the stimulus of fertilization is not necessary—we learned in Chapter 16 that the infertile eggs of queen bees go ahead and form embryos which becomes drones. Thus the drone bees carry only one set of chromosomes and one set of genes in their body cells, while the female bees have the more common double set because they come from fertilized eggs. A similar development of unfertilized eggs has been accomplished experimentally in other animals. If a frog's egg is pricked with a needle covered with blood serum it will begin embryonic development and in some cases will develop into a mature frog. Sea urchin eggs placed in strong salt solution and then returned to normal

sea water will undergo embryonic development. Rabbit eggs can be treated with salt water, ice water, and pin pricks to stimulate the beginning of such development. In one case, at least, one of these developing embryos was transplanted into the body of a virgin female rabbit and it developed and was born as a normal-appearing female (Fig. 31.8).

These experiments show that the sperm does not bring some substance into the egg which stimulates the changes leading to the cleavages. Rather it would appear that the egg has within itself a reaction system which is all ready to operate when the proper stimulus is applied. The sperm normally applies this stimulus, but experiments show that it can be applied in other ways. It may be that there is some enzyme within the egg which is held in a bound form; but, when released by the presence of the sperm or by experimental means, this enzyme brings about the changes which are associated with early embryonic development.

Genes and Ancestry

It will be noted from the events described in this chapter that an individual receives only one half of the genes possessed by each parent. The other half are irretrievably lost. A person can never express those lost genes in himself or in any of his descendants unless they are brought in by other persons through marriage. Also, since each parent received half of his genes from his parents, it is evident that every person receives approximately one fourth of the genes possessed by each grandparent, an eighth from each great grandparent, and so on. You may have had an ancestor that came over in the "Mayflower," but the proportion of this ancestor's genes in your cells is quite small in comparison to those received from the hundreds of other ancestors of the same period who transmitted their genes to you. Each of these others contributed just as much even through he or she may have suffered a witch's death in Salem, ended life on a hangman's noose, or finished life in an insane asylum. Genes are no respectors of persons.

REVIEW QUESTIONS

1. A human egg is thousands of times larger than a human sperm, yet children tend to inherit equally from each parent. Explain.
2. Why did the theories of heredity before the seventeenth century fail to take account of the role of sperms and eggs?
3. How did Weismann's germ plasm theory of inheritance differ from Darwin's theory of pangenesis?
4. What was the contribution of Mendel to an understanding of inheritance?

5. How does meiosis differ from ordinary mitosis?

6. How does spermatogenesis differ from oogenesis?

7. Man has 48 chromosomes as his normal diploid number. How many chromosomes would there be in: a primary spermatocyte, an egg, a cell of the skin, a secondary spermatocyte, a polar body, a sperm?

8. Why are eggs much larger than sperms?

9. What prevents more than one sperm from entering an egg in fertilization?

10. There have been a few cases where eggs, which normally are fertilized, have been induced to develop experimentally without fertilization. What is there about the egg that makes this possible?

11. Is it conceivable that a sperm could ever be induced to develop into an embryo without an egg? Give reasons for your answer.

12. In surveying your ancestry, suppose you find that George Washington was your great, great, great, great grandfather. By the law of averages, what proportion of your genes would be expected to have come to you from this illustrious father of our country?

32

The Principles of Heredity
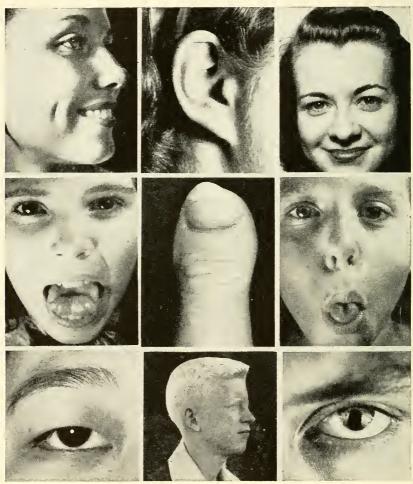
The influence of heredity is universally recognized. A child will show physical characteristics, mannerisms, and abilities of a father that he may have never even seen. Fine race horses transmit their qualities for speed and endurance to hundreds of offspring which develop into champions of the race tracks. Good hunting dogs are bred together to produce offspring with the same fine qualities for seeking out and retrieving game. Any plant or animal breeder knows the importance of heredity—he would never hope to produce prize-winning beef cattle from scrub ancestry or champion egg-layers from ordinary barnyard chickens.

In spite of the recognized importance of heredity, however, its simple principles are often not fully understood. When a child shows some striking difference from its parents, such as blue eyes from brown-eyed parents, it may seem as if heredity is a capricious thing, working at some times and suspending its operations at other times. Heredity may seem to be unstable, unpredictable, and of a mysterious nature. Mystery cannot long withstand the cold light of scientific research, however; and intensive investigations in the field of genetics have shown us that heredity is stable and that its results can be predicted with mathematical precision. A blue-eyed child with brown-eyed parents is not an exception to heredity—it is a normal result of the laws of heredity under certain circumstances. It would be an exception only if we did not get a certain proportion of blue-eyed children from brown-eyed parents of this nature. In this chapter we will study some of the principles underlying heredity which explain many of our everyday observations on this subject.

Dominance and Recessiveness

The method of gene action in heredity can probably best be understood if we first consider the influence of a single gene on a particular character and learn how it is transmitted and expressed. Then, since other genes follow a similar pattern we will have a general understanding of them all. We are naturally intensely interested in human heredity, but

human inheritance is not a good place to start such a study. Most of our knowledge of heredity has come from experimental breeding of plants and animals with differing characteristics. Human beings cannot thus be bred experimentally and, even if they could, they have such a long generation cycle and so few offspring they would not be good

Fig. 32.1. Some physical characteristics which are inherited in man. From left to right and top to bottom these are: Dimpled cheeks (dominant). Attached ear lobe (recessive). Widow's peak, a point of the hair line which extends down in the center of the forehead (dominant). Ability to fold the tongue (dominant). Clubbed thumb (dominant). Ability to roll the tongue (dominant). Mongolian eye-fold, upper eyelid folded downward (dominant). Albino (recessive). Elongated pupil of the eye (dominant).

subjects for genetic experiments. We, therefore, turn to some form of animal life that is easily obtained, easy to feed and care for, that has a short life cycle, and that bears rather large numbers of offspring. Principles learned by such breeding can then be applied to human heredity.

Suppose we chose guinea pigs as our experimental animals. We first select a male with a black coat that has descended from a group that has had black coats only for many generations. We mate this with a female with a white coat that has come from an ancestry of pure white coats. This is known as a **monohybrid cross**—a cross of animals differing with respect to only one inherited characteristic. (Of course there are bound to be other minor differences, but we ignore these in our study.)

When the offspring appear from this cross, we find that they are all black and they show no distinguishable difference in coat color from the black male parent. Thus black appears to dominate over the white, and we say that the gene for black-coat in guinea pigs is **dominant.** Since the white gene fails to express itself under such conditions, it is said to be **recessive.** Suppose we now allow these black guinea pigs of the first generation to mate among themselves. When the next generation appears, we find both black and white guinea pigs—about three fourths black and about one fourth white. Thus, we can see that the gene for white was not lost when it failed to express itself in the first generation—it was merely dormant and was able to produce the white coats of some of the guinea pigs in the second generation.

These results may appear somewhat puzzling at first, but a study of the genes reveals the answer. We have already learned that there are two genes of each kind in the body cells. These genes occupy similar positions on homologous chromosomes. Thus, in one chromosome of the guinea pig there is a gene which is concerned with the deposition of pigment in the hairs of the body. When we find the homologous mate to this chromosome there will be another gene in the same position which also influences pigment deposition. These two genes may be the same or they may be different in their expression. In the original black male which we used for our cross, both of these genes were for a black coat. The original white female, on the other hand, had both genes for a white coat. We say that these two guinea pigs were pure, or **homozygous,** for their respective coat colors. When meiosis took place in the male, sperms were produced, each of which carried one gene for black. Likewise, meiosis in the female produced eggs, each of which carried one gene for white. When the sperms and eggs united, each zygote which was formed contained one gene for black

and one for white. In this case the single black gene is able to produce the black pigment in the hairs, and the offspring are all black. These coats are just as black as if they had two genes for black, but since each cell carries a white gene in a dormant condition, we say that these guinea pigs are impure black, or **heterozygous.**
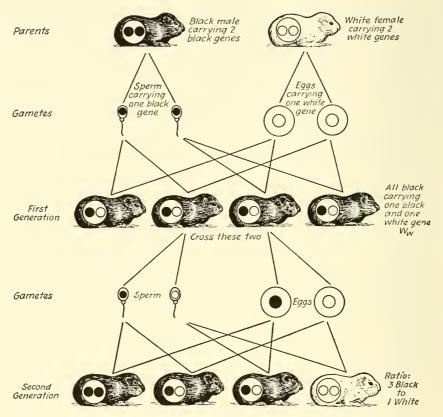
Fig. 32.2. A monohybrid cross in the guinea pig. The genes for black coat color are represented by the black circles, and the genes for white coat color are represented by white circles. Note how the gene for black dominates over the recessive gene for white.

When meiosis takes place within the gonads of these heterozygous guinea pigs, the genes for black and white are separated, so that one half of the gametes will contain a gene for black and the other half will contain the gene for white. Fig. 32.2 shows the various combinations of genes which result when these heterozygous guinea pigs are crossed with one another. It can be seen from this diagram that about one fourth of the offspring will receive two black genes, about one half

will receive one gene of each kind, and the remaining one fourth will receive two white genes. Since both the homozygous black and the heterozygous black will have black coats, however, they cannot be distinguished by simple observation. Hence, the second generation ratio of three black to one white is obtained.

If we wish to test the black guinea pigs of this second generation to determine which are heterozygous and which are homozygous, we can breed them individually to white mates. The homozygous blacks will give all black offspring from such a cross, but the heterozygous blacks will give one half black and one half white. This can easily be demonstrated by making a diagram of such a cross. For convenience, we usually use letters as symbols for genes in such crosses—in this case we allow w to represent the gene for white and W to represent the gene for black.

Genetic Ratios

We should introduce a word of explanation at this point about genetic ratios, because they are often misunderstood. When we say that a certain type of cross yields a three to one ratio, this does not mean that for every four offspring there will be three of one type and one of another. A ratio indicates the results which have been worked out on the basis of mathematical probability and which will be approximated when large numbers are considered. We all know that the chance of obtaining a head when a penny is tossed is one half and the ratio of heads to tails in a number of tosses is one to one. Yet it is entirely possible that we can toss four pennies and get four heads. Each toss is purely a matter of chance and bears no relationship to the other tosses that have been made. Likewise, a heterozygous brown-eyed man married to a blue-eyed woman would expect a one to one ratio in eye color among his children. Suppose the first child had blue eyes. The chance of having a blue-eyed child at the second birth would still be one half, just as if there had been no first child. One half of the man's sperms carry the gene for blue eyes and one half carry the gene for brown eyes; all the eggs have the gene for blue eyes. Hence, it depends upon which of the two types of sperms reaches the egg first. These millions of threshing sperms in their race for the egg have no way of knowing that this couple have already had a blue-eyed child, and a sperm carrying a gene for blue eyes is just as likely to win the race as one carrying the gene for brown eyes. If the second child did have blue eyes, then the same would be true for the third child, and so on. The couple thus might easily have four children with blue eyes. How-
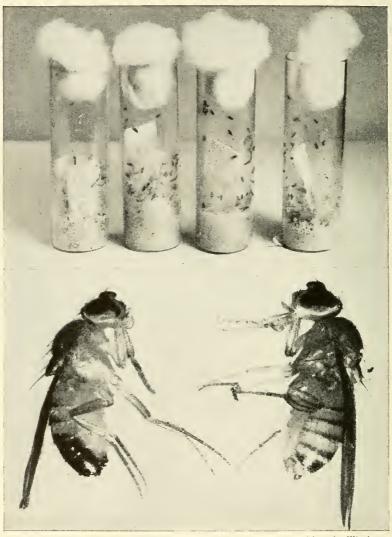
FIG. 32.3. The fruit fly, *Drosophila melanogaster*, a valuable animal for genetic research. The upper picture shows the vials containing larvae, pupae, and adults; the lower picture shows a male on the left and female on the right, greatly enlarged. These flies are ideal for genetic experiments; they are easily raised in small vials, require little food, have a life cycle of only about ten days, and exhibit many easily recognized hereditary distinctions.

ever, and this is the important point, if we tabulate the eye color of thousands of children from many families with the particular gene combination of this couple, we shall find that almost exactly one half of them will have blue eyes and the other half will have brown eyes. The law of averages works out, and the ratios can be expected to run very true in such large numbers.

This illustrates the advantage of using animals that bear large numbers of offspring for genetic studies and again shows why human beings are poor subjects for such studies. We can study a large number of pedigrees of human families, however, and compare the results with those obtained by breeding experiments with other animals and thus learn much about human heredity. Probably the majority of the information we have on heredity has come from genetic crosses of the tiny fruit fly, *Drosophila,* which we commonly see buzzing around garbage cans during warm weather. A single pair of these flies in a small vial with a few cents' worth of corn meal or banana food will yield a hundred or more offspring within about ten days' time. These are sufficient to obtain reliable ratios. Information obtained by such crosses has unlocked many of the secrets of heredity in other forms of life including man.

Intermediate Genes

There are some characteristics which are influenced by genes which are neither dominant nor recessive, but intermediate in their effect when heterozygous. As an example, if we cross a pure white, short-horned cow with a pure red, short-horned bull, the resulting calf will be neither red nor white, but roan. Roan is a color which is an intermediate expression of the red and white genes. Neither of the genes is dominant over the other and both are partially expressed. When roan cattle are crossed together, the offspring are red, roan, and white in the ratio of $1:2:1$. This shows that the genes do not mix and that there is not a specific gene for roan.

One of the most interesting cases of intermediate inheritance in man is concerned with the blood types. When a person with type A blood, who is homozygous, marries a person with type B blood, who is homozygous, all of their children will have type AB blood. Neither the gene for type A nor the gene for type B is dominant, so both blood antigens are formed. When two persons with type AB blood marry they will have children with type A, type AB, and type B blood in the $1:2:1$ ratio. The gene for type O blood, on the other hand, is recessive to both the gene for type A and the gene for type B. Hence, if a homozygous type A person marries a type O person, all of the children
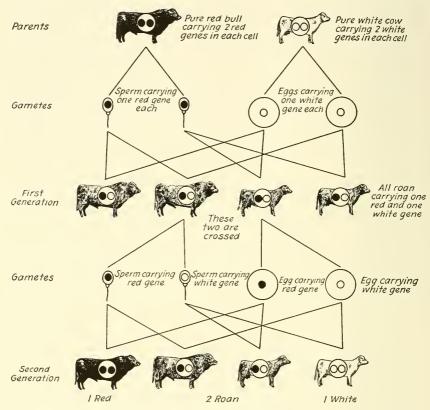
FIG. 32.4. Diagram showing intermediate inheritance of hair color in short-horned cattle. Note that the combination of red and white genes gives roan.

will be type A. Thus, we have both intermediate and dominant-recessive inheritance in the case of the genes for blood types in man.

Independent Segregation of Genes

When two or more genes are traced at the same time it is usually found that they follow the pattern of the monohybrid crosses independently of one another. We can make another cross with guinea pigs to illustrate this important fact. There is a pair of genes which influence the length of the hair on the body. The dominant form of this gene produces short hair and the recessive form produces long hair. Now, suppose we cross a guinea pig that has black short hair (homozygous for both pairs of genes) with a guinea pig that has white long hair. We know that the latter is homozygous for both genes because

both are recessive, and only those guinea pigs which are homozygous for recessive genes will express the effects of these genes. The first generation will all have black short hair, but will be heterozygous for both pairs of genes. When these are crossed among themselves we obtain the interesting ratio of 9 black short : 3 black long : 3 white short : 1 white long. Fig. 32.5 shows how the gametes are assorted to give this result.
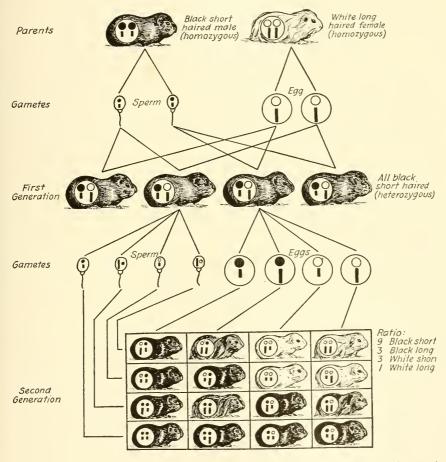
FIG. 32.5. A dihybrid cross. A homozygous, black, short-haired guinea pig is mated with a homozygous, white, long-haired guinea pig. All of the first generation are black and short because these two genes are dominant over the white and long. When two of these first-generation guinea pigs are mated, the gametes combine to give 9 black short, 3 black long, 3 white long, and 1 white long in the second generation. This type of cross illustrates the principle of independent assortment of genes.

These results show the independent action of each gene. The genes for hair color and hair length do not stay together as they were found in the original parents. We have a 3 : 1 ratio for each character, but there is an independent assortment which produces new combinations as well as the old combinations. This explains why children show various mixtures of inherited characteristics from their parents and why there is variation among the children of the same parents. We might compare the segregation of the chromosomes in meiosis to the shuffling and dealing of a deck of cards. Each gamete represents a new deal and will not be exactly like other gametes in its gene content.

Linked Genes and Crossing Over

If you have been studying the principles of independent segregation of genes thoughtfully, you have already realized that there must be some cases where such free assortment of the genes does not occur. The number of genes within a cell is always much greater than the number of chromosomes, so each chromosome must bear many genes. Chromosomes are assorted independently during meiosis and genes on different chromosomes will likewise have such independent assortment; but what about two genes that lie on the same chromosome? In this case we would expect the genes to remain together during meiosis and retain the parental combinations in the future offspring. **Dihybrid crosses** involving genes lying on the same chromosome indeed show that such linkage does exist—the genes will tend to stay together in the same combinations in which they existed in the parents of the first generation. This linkage, however, is usually not complete—there will very likely be a few new combinations in the offspring of the second generation.

Let us take a cross in *Drosophila* to illustrate **linkage.** Suppose we select a male with a gray body and red eyes and cross it with a female with a black body and purple eyes. The first generation flies will all have gray body and red eyes, which shows that these two genes are dominant. Now let us chose some of the females of this group and cross them with males having black body and purple eyes as a test cross. In the flies obtained from this second cross, let us assume that we get results as follows: 92 gray red, 96 black purple, 5 gray purple, and 7 black red. Since the predominating types are like the first parents it is obvious that these two pairs of genes are linked, but where did we get the recombinations?

Cytological studies help us learn the answer. When chromosomes pair during the early stages of meiosis it can be seen that portions of

chromatids of opposite chromosomes sometimes trade places. This is a process known as **crossing-over,** and through it a group of genes on one portion of the chromosome may become joined to genes lying on the opposite chromosome. In this way the recombinations of genes can take place. In the *Drosophila* cross we found about 6 per cent of the

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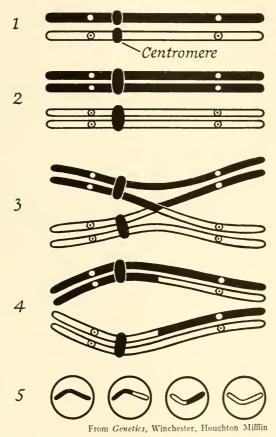
FIG. 32.6. Method of chromosome crossing over during the first division of meiosis. The paired chromosomes (1) become duplicated (2) and there are now four chromatids. Crossing over takes place (3) when one chromatid of each chromosome breaks and becomes reattached to a portion of a chromatid of the opposite chromosome. These pull apart in the anaphase (4). The last figure (5) shows the four chromosomes after the second division of meiosis.

flies in the second generation represented such recombinations. This number will vary in accordance with the distance between the genes on the chromosome, since there will be a greater chance for crossing over between genes lying far apart than for those lying close together. Because

of this it is possible to determine the positions of genes on the chromosomes and the relative distance between different genes on the chromosomes of those forms of life which have been studied thoroughly from a genetic standpoint.

Crossing over is of great value in the establishment of desirable genes through the rigorous process of natural selection. If all of the genes lying on one chromosome were inseparably linked, then selection would have to be on the basis of entire chromosomes. Every chromosome certainly will contain some genes which are good and some which
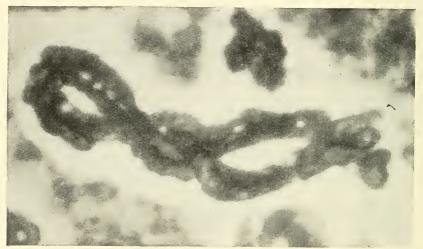
Fig. 32.7. Crossing over as seen in living cell from grasshopper testes. This highly magnified photomicrograph shows a pair of chromosomes in the prophase of the first division of meiosis. The two chromatids which make up each chromosome can be seen. Note that crossing over has taken place between opposite chromatids at four places.

are not good in their effects. Through crossing over the desirable genes may be separated from the undesirable, and through natural selection the good may become widely established while the undesirable genes are reduced in numbers. Thus, crossing over allows natural selection to take place on the basis of individual genes rather than on the basis of the total influence of entire blocks of genes which lie on the same chromosomes.
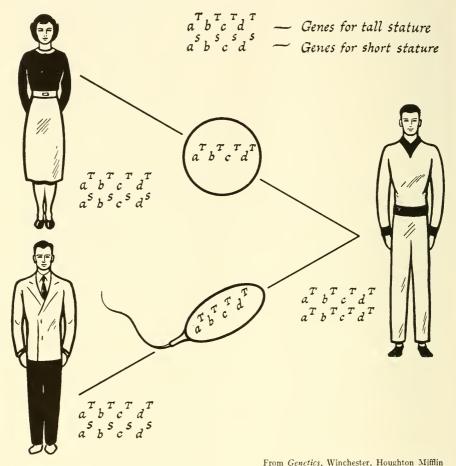
Multiple Genes and Quantitative Characteristics

Common observation readily reveals the fact that all of the inherited characteristics of living things do not follow the pattern of simple

dominant-recessive or intermediate inheritance. We know, for instance, that height in man is influenced by heredity; yet we do not have just tall people and short people as would be the case if it were simple dominant-recessive inheritance. Neither could we assume intermediate inheritance from the influence of a single gene, for body height does not fall into three sharply defined classes. There are many gradations of height. Of course, environment in the form of food, disease, etc., plays its part, but the genes determine the basic potentialities of growth. To understand the method of inheritance of such quantitative characteristics does not require a study of a new type of gene or a new method of inheritance—it is simply explained on the basis of multiple genes.

Body height in man results from a complicated interaction of a number of different factors. If a person receives a good proportion of the genes which favor extended skeletal growth, he will be above average in height; and vice versa if more genes for short stature are received. Through independent segregation of the genes in the reproductive cells of his parents a brother or sister may get a different proportion of the two and show a marked difference in height. Fig. 32.8 shows how such segregation can operate to produce a tall child from parents of medium height. In general, however, the average adult height of all the children of a couple will approximate the parent height, although it may run a little greater due to the better environmental conditions which the children of the present generation have enjoyed. Also, in any comparisons of height in human beings it is important to keep the influence of sex in mind. Because of the earlier physical maturity of the female, a woman's adult height will be several inches less than it would have been had she been a man. To convert a woman's height into a figure that will compare with that of a man it is necessary to multiply her height by 1.08.

The inheritance of skin color in man is another case which illustrates the influence of more than one gene on a characteristic. There seem to be two pairs of genes involved in the skin color differences between the Negro and the white races. Thus, a white person would carry four genes for the white-type skin color and the Negro would carry four for the Negro-type pigmentation. When there is an interracial marriage, mulatto children are produced which have an intermediate type of skin color. Each of these children will receive two genes of each type, and both are intermediate in their expression. Among the children of two mulattoes, on the other hand, the genes become independently assorted to give five different classes of skin coloring, ranging from white to the Negro type. If this is worked out as a dihybrid cross the ratio of the shades of skin color will be $1:4:6:4:1$. There are certainly other genes

$a^T b^T c^T d^T$ — *Genes for tall stature*

$a^S b^S c^S d^S$ — *Genes for short stature*

$a^T b^T c^T d^T$

$a^T b^T c^T d^T$
$a^S b^S c^S d^S$

$a^T b^T c^T d^T$

$a^T b^T c^T d^T$
$a^T b^T c^T d^T$

$a^T b^T c^T d^T$
$a^S b^S c^S d^S$

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FIG. 32.8.   Medium-sized parents can have a tall child when the genes for tall stature become segregated into the reproductive cells from both parents during meiosis.

which influence skin coloration, but these two genes seem to be the ones involved in the differences between the white and Negro races.

Most inherited characteristics are probably influenced by a number of different genes working together. Since we often find variations in only one of the gene pairs involved, however, it may appear as if this is the only gene involved. Also, we know that one gene may influence more than one characteristic. As an example, there is one gene which, when homozygous in man, causes some defect in the metabolism of one of the amino acids (phenylalanine). As a result, there is an accumulation of an acid (phenylpyruvic acid) in the system which is excreted

in the urine. In addition, the persons with this condition have very light colored hair and are imbeciles. Here we have three widely divergent effects from one gene. They are all tied together, however—the defect of metabolism somehow fails to provide the energy necessary for normal brain reactions or the materials for normal pigment production in the hair. No doubt many genes have multiple effects because of such a chain reaction.

Sex Determination

When we stop and think of it, is it not remarkable that children of the same parents can show the great differences which are found between members of opposite sexes? The sex organs, of course, are quite divergent, but there are other differences that extend to practically every part of the body. The skin of a woman has a texture and internal structure which differs from that of a man. Her skeleton is modified in the pelvic region in a manner which permits normal child birth. This leads to modifications of the angle of the hip bones and the knee bones and similar differences are found in the shoulder and elbow joints. A woman's facial bones are broader in proportion to skull height than those of a man. Her muscles have a greater deposit of fat among the muscle fibers which makes them softer and helps to give the flowing lines that characterize a woman's figure. There are blood differences, differences in the growth of face and body hair, and differences in the degree of development of the mammary glands. The differences also extend to physiology—the rate of metabolism, rate of respiration and heart beat, blood pressure, and nervous reactions all vary with sex.

With even this incomplete list it is readily apparent that sex differences cannot be explained on the basis of simple monohybrid inheritance nor through multiple genes as we have studied them. Genetic evidence indicates that every person has all of the genes for both sexes, but under normal circumstances only those genes for one sex express themselves and the others are suppressed. The bearded lady of the circus and a man with fully developed feminine breasts are examples of those rare cases where certain of the genes seem to break through and show in a sex in which they are supposed to be suppressed. It is quite possible that homosexuality is another case of displaced emphasis on genes influencing sexual attraction.

We now need to find the mechanism which will suppress the genes for one sex and allow the others to be expressed. We know that the **sex hormones** play a part in the vertebrate animals. If we remove the ovary from a young female chick and engraft testes from a male chick,

this bird grows into something looking exactly like a rooster. It will even crow and try to mate with females. The source of the female sex hormone was removed when the ovary was taken out and the engrafted testes produced the male hormone. This caused suppression of the female genes and expression of the male genes. If testes are engrafted into young female chicks without removal of the ovaries there will develop a peculiar combination of characteristics of both sexes because of the influence of both hormones. There has even been one recent
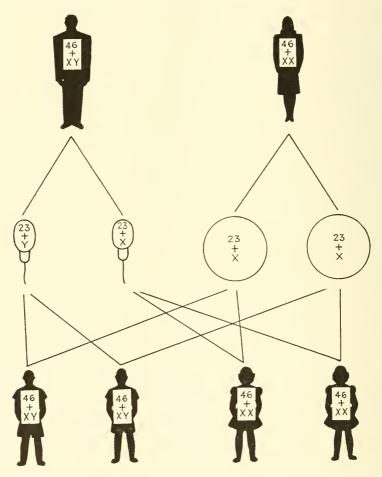
FIG. 32.9. Sex determination in human beings. All persons carry 48 chromosomes in their body cells. These include two X-chromosomes in a woman and an X and a Y in a man. When gametes are formed the eggs all carry an X-chromosome, while half the sperm carry X-chromosomes and half carry Y-chromosomes. Sex is determined by the type of sperm that fertilizes the egg.
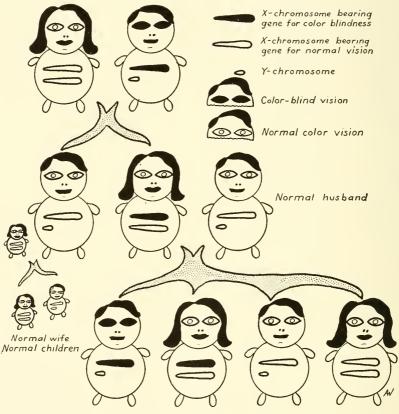
case where a mature man was transformed into a rather convincing replica of a woman by testes removal and injections of the female sex hormones.

Hormones cannot offer a complete explanation for sex determination, for there still must be some factor to start sex in one direction or the other. We must go back to the chromosomes to find this. When we examine the chromosomes within the cells of the body of a woman we find 24 perfect pairs, but in the cells of a man we can find only 23 matched pairs and one pair which is unequal in size. The large one of this unequal pair is called the X-chromosome and the small one the Y-chromosome. These are known as the **sex chromosomes.** One of the 24 pairs in the female consists of two X-chromosomes. Experiments with a number of different kinds of animals show that this chromosome difference is the basis for determining sex. Two X-chromosomes establish a balance with the other chromosomes which favors the female-determining genes, while a single X-chromosome establishes a balance which favors the functioning of the male-determining genes. The Y-chromosome seems to play no part in sex determination.

In spermatogenesis, the 48 chromosomes are separated so that one half of the sperms have an X-chromosome and the other half have a Y-chromosome as one of their 24. The eggs, of course, all bear an X-chromosome as one of their 24. When an X-bearing sperm fertilizes the egg the zygote will have two X-chromosomes and a girl will result. A Y-bearing sperm on the other hand results in the XY combination in the zygote and this produces a boy. Since these two types of sperms are produced in approximately equal numbers, the balance of the sexes is maintained.

Only the vertebrates appear to have sex hormones which play their part in sex determination as we have described it. Among most of the invertebrates with separate sexes, however, the chromosome mechanism operates to do the job alone. In the fruit fly, *Drosophila,* for instance, there is the **XY method** of determination as in man. There are a few forms of life, however, in which there is a reversal of the chromosome arrangement. In birds, moths, butterflies, and some fish the unlike pair of sex chromosomes is found in the female and the like pair in the male. Thus, the sperms are all alike and the eggs are of two different types with regard to sex chromosomes. In order to avoid confusion, these are sometimes called **WZ** in the female and **ZZ** in the male. The **honey-bee** and a few similar insects have a distinctive method of sex determination—fertilized eggs develop into females and unfertilized eggs develop into males (see Chapter 16).

Finally, mention should be made of a few forms of insects, such
as the grasshopper, which have what is called the **XO** method of sex
determination. In these forms the method is exactly like the XY
method except that the Y-chromosome is lacking. The female grass-
hopper has 24 chromosomes as a diploid number which includes a pair
of X-chromosomes, but male grasshoppers have only 23 chromosomes,
including only one X-chromosome. All eggs carry the X, but only one
half of the sperms carry the X—the other half carry only 11 chromo-

One-half of sons are color-blind

FIG. 32.10. Sex-linked inheritance. When a color-blind man marries a woman who
does not carry the gene for color blindness, all of their children will be normal in their
color vision. The daughters of such a couple, however, will carry the X-chromosome
from their father, and this chromosome bears the recessive gene for color blindness.
When such a daughter marries a normal-visioned man, one-half of her sons will be
color-blind and one-half of her daughters will carry the gene, but will have normal
    vision. Note that the men cannot carry the gene unless they are color-blind.

somes. The X-carrying sperms produce females, while those sperms without an X produce males.

Sex-Linked Inheritance

Some of the genes on the X-chromosome (or Z-chromosome) are directly concerned with sex determination, but the majority of them are similar to the genes on the other chromosomes. They affect many characteristics which have nothing to do with sex. In man, for instance, there is a gene on the X-chromosome which is concerned with color vision. There is one recessive form of this gene which produces defective color vision known as **color blindness.** Persons who express this gene have difficulty distinguishing between red and green. There is no counterpart of this gene on the Y-chromosome. Most of the genes on the X-chromosome in a man are present in the single (haploid) condition, because the smaller Y-chromosome does not possess the homologous genes. This means that a man will express these genes regardless of whether they are dominant or recessive when they are present in pairs in the female. Therefore, if a man receives a gene for color blindness from his mother he will be color-blind for he does not receive a partner for this gene from his father. A woman, on the other hand, must receive a gene for color blindness from both parents, for this gene is recessive to the gene for normal color vision. Because of this there are always more color-blind men than women with this affliction—there are about sixteen color-blind men to one color-blind woman. Fig. 32.10 shows how inheritance of sex-linked characteristics is diagramed.

Hemophilia is another human characteristic which is sex-linked. This is something called "bleeders" disease because the blood clots very slowly, and there is excessive bleeding whenever an injury occurs. This gene occurs in some of the royal families of Europe and causes many an untimely death among the males of this line.

REVIEW QUESTIONS

1. What is meant by the expression "dominant" and "recessive" as applied to inherited characters?
2. By means of a diagram show how a white guinea pig can be produced by a cross between two black guinea pigs.
3. Suppose you have some cats that are gray and some cats that are yellow. Tell how you would breed them to determine which of these two characters is dominant and which is recessive.
4. Short hair is dominant to long hair in guinea pigs. Show the results of a cross between a pure (homozygous) short-haired male and a pure long-haired female.
5. Cross the offspring from problem 4 among themselves and show the expected results.

6. What are the expected types of offspring from a cross between a heterozygous black, short-haired guinea pig and a homozygous white, long-haired guinea pig? Show how you derive your answer.

7. How can the inheritance of quantitative characters be explained on the basis of the gene concept?

8. Why are genetic ratios more reliable when there are large numbers of offspring?

9. By means of a diagram show the expected results of a cross between two roan short-horned cattle.

10. Under what conditions are two genes said to be linked?

11. What is the possible biological value of crossing over?

12. What is the relation between hormones and chromosomes in sex determination in the vertebrate animals?

13. How does sex determination in birds differ from that in man?

14. Show the types of children that will be expected to result from a marriage of a color-blind woman with a normal-visioned man.

15. A normal man marries a normal woman who has a father with hemophilia. Show the kinds of children which may be expected.

33

The Development of the Individual

Embryology

The bodies of the more advanced animals are composed literally of billions of cells, showing a great variety of shapes, sizes, and functions. Yet, each of these animals started its life as a single cell, zygote, and the adult has been produced by repeated duplications of this cell together with the proper differentiation and integration of the cells produced. In this chapter we shall learn something about the origin of the different tissues and organs, primarily in the chordates. This is not an easy study, because many complex reactions take place as the genes of the cells exert their influence and bring about an orderly arrangement of the mass of protoplasm which appears during embryonic growth. Also, there are many phases of this development which are not yet fully understood; but our understanding is increasing rapidly, especially in the light of recent physiological experiments in this field.

There are similarities in the embryonic development of the different classes of chordates, but there are also differences due primarily to the amount and distribution of yolk in the zygote and to the conditions under which the embryo develops. We can understand the entire group better, perhaps, if we first study the embryogenesis of a simple chordate, such as Amphioxus, and then show how other chordates differ from this form.

Early Cleavage

After the egg is fertilized (see Chapter 31) a zygote results which usually undergoes its first mitosis within about an hour. The two cells which are formed adhere to one another and a second division follows shortly. Since both cells usually divide at about the same time, we now have a group of four cells. This is followed by a third division of each of these cells to give eight. Other divisions follow and give 16, 32, and 64 cells. At about this time most embryos lose their synchronization of cell division and there is no longer a doubling of cells at regular intervals. When the embryo is at about the 16-cell stage, the cells are

grouped together into a mass which somewhat resembles a mulberry and is called the **morula,** which is the Latin name for mulberry.

The Formation of Blastula and Gastrula

As divisions continue, the cells arrange themselves in the shape of a hollow ball which is known as the **blastula.** The cavity within the ball is the **blastocoel.** This ball is usually formed at about the 64-cell stage. During all of these cell divisions there has been practically no growth, and the total mass of cells in the blastula has a volume no

Zygote   2-cell stage   8-cell stage

Morula   Blastula   Gastrula
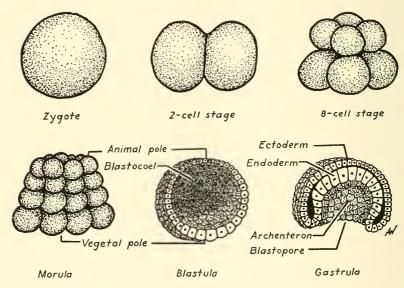
FIG. 33.1. Early embryogenesis of a simple chordate (Amphioxus). The zygote divides and forms 2 cells which adhere. After two more divisions the 8-cell stage results. The next drawing shows the morula at the 32-cell stage. The cells at the animal pole are somewhat smaller than the cells at the vegetal pole. The blastula is shown next with the ball of cells cut open to show its hollow interior. The gastrula is shown in the final drawing; there has been an invagination at the vegetal pole with the formation of the archenteron.

greater than the one cell of the zygote. If a section is cut through the blastula, it can be seen that the cells at one region of the ball are slightly larger than the cells opposite them. The larger cells represent the **vegetal pole;** and the smaller, opposite cells represent the **animal pole.** As division continues, the cells of the vegetal pole begin dividing faster than the other cells and push up inside the ball and form an invagination.

To aid in visualization, compare the embryo with a hollow, soft rubber ball into which you have pushed your finger to cause an invagination. This invaginated embryo is called the **gastrula.** The invagination continues until it reaches all the way across the ball. The embryo is now shaped like a tube within a ball. The tube is called the **archenteron** and is destined to form the inner portion of the alimentary tract. The opening of the archenteron at the point of original invagination is called the **blastopore** and will eventually be the region of the anus. The cavity within the archenteron is the **gastrocoel.** There are now two distinct body layers—the outside layer of cells is known as the **ectoderm,** and the cells forming the tube within the ball make up the **endoderm.** This stage of development is suggestive of the diploblastic type of animals that never have more than two body layers even in their adult form. When a hydra contracts into a little ball it is somewhat like an embryo of a chordate at this gastrula stage.

Formation of the Mesoderm and the Coelom

Since the chordates are triploblastic animals, there is still a third layer, the **mesoderm,** which must be formed before the various body
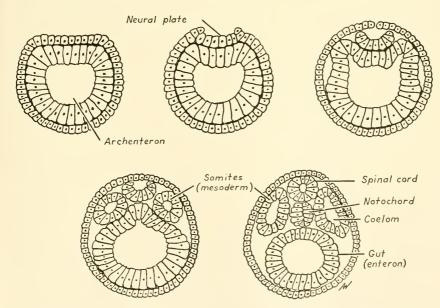
FIG. 33.2. Formation of the mesoderm, coelom, and nerve cord in Amphioxus. These drawings represent a cross-section through the gastrula and post gastrula as the somites and notochord pinch off from the endoderm while the spinal cord is formed from an invagination of the ectoderm.

organs can develop. The mesoderm is produced from the endoderm by means of paired pouches. These form on the dorso-lateral margins of the gut (archenteron) and gradually pinch off from the endoderm until they lie free between the ectoderm and the endoderm. The pouches extend both dorsally and ventrally until they meet above and below the digestive tube and in this way form the dorsal and ventral mesenteries. The pouches later connect with each other and form a single cavity, the **coelom.** At about the same time a third evagination of the endoderm occurs along the dorsal side of the gut. This pinches off and forms a long slender rod of cells which develops into the **notochord.** Since it is formed at the same time and in the same way as the mesoderm, most embryologists agree that the notochord should also be considered as a mesodermal structure.

Variations in Cleavage of the Chordate Zygote

The size of the egg, the amount of yolk, and the distribution of the yolk all influence the exact method of cleavage of the zygote. The method which we have described applies where there is a relatively small amount of yolk, and that which is present is evenly distributed in the zygote. In some chordates (amphibians, cyclostomes, and some primitive fishes such as the gars) the amount of yolk is somewhat large, and it is concentrated in the half of the zygote around the vegetal pole. This half of the zygote will be light in color and is known as the **vegetal hemisphere,** whereas the darker half will be the **animal hemisphere.** The first two divisions are equal and split the zygote into four cells, each of which includes one fourth of the animal and one fourth of the vegetal hemispheres. The third division, however, cuts across the zygote up nearer the animal pole, and the four cells of this region are smaller than those at the vegetal pole. The yolk at the vegetal pole seems to interfere with the division of the cells, and the cells at this region divide more slowly than those at the animal pole. Consequently, as division continues there are more and smaller cells around the animal pole. As the blastula is formed we find that the blastocoel is nearer the animal pole than the vegetal pole. When time comes for formation of the gastrula, we find that the cells at the vegetal pole are so large that there can be little invagination as was found in Amphioxus. There is a slight invagination, however, and then the cells from the animal hemisphere begin growing down over the sides of the vegetal hemisphere. In time they completely cover this vegetal hemisphere with the exception of a small round area. This area is the equivalent of the blasto-

Foundations of Biology, Woodruff, The Macmillan Company
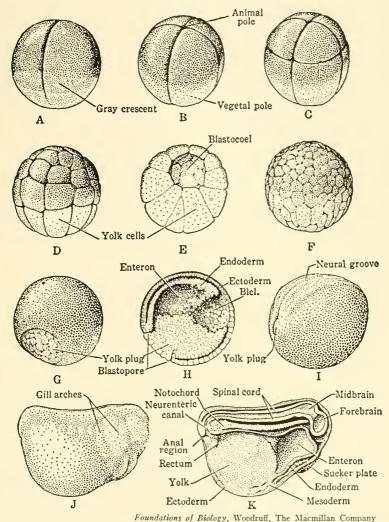
FIG. 33.3. Early embryology of the frog. Note the unequal type of total cleavage due to the concentration of yolk at the vegetal pole.

pore, but it is not a pore at all because it is filled with the yolk-bearing cells which form the **yolk plug.**

In some chordates the amount of yolk in the zygote is so great that there can be no total cleavage, but rather there is **partial cleavage** which does not divide the entire zygote. This type of zygote is found in the higher fishes, birds, and reptiles. If we consider the fertilized hen's egg as an example, the part which we call the "yolk" is the true zygote.

The "white of the egg" and the shell are merely envelopes that surround this zygote. The nucleus containing the chromosomes is found in a small **germinal disc** which lies on the surface of the yolk. After the first mitosis, the cleavage furrow forms between the two nuclei and then stops. The great mass of yolk beneath seems to be too great a barrier for the furrow to penetrate. As divisions of the nuclei continue, however, cell membranes are formed beneath and, as a result, we have a group of small cells on top of the yolk. This group of cells is called the **blastodisc**. Soon the blastodisc pulls away from the yolk in the center, but remains attached around its margin and forms something like a blister, the blastoderm. This produces a cavity between the blasto-
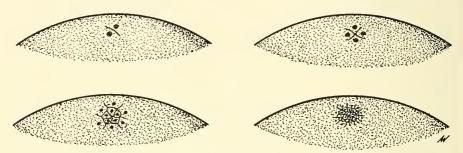
FIG. 33.4. Partial cleavage of the chick zygote. These diagrams show only a small portion of the large yolk of a fertilized egg. The first cleavage furrow does not extend through this great mass of yolk, but remains only on the surface separating the two nuclei. As the nuclei continue divisions, cell membranes are formed beneath as well as between the nuclei and a group of cells (the germinal disc) on top of the yolk results.

derm and the yolk which is the **blastocoel**. We now have the equivalent of the blastula. Next, the blastoderm separates from the yolk at one point and this forms the **blastopore**. The **endoderm** now appears as cells invaginate at this region, or they may proliferate directly from the ectoderm.

In the posterior part of the blastoderm, the ectoderm thickens and forms an area known as the **primitive streak**. There is a primitive node at the anterior end of this streak which lays down the cells which form the notochord. This node regresses posteriorly as the cells of the notochord are laid down so that when the notochord is formed it lies anterior to the node. Then the ectoderm thickens above the notochord and forms the **neural plate** which is to produce the brain and spinal cord. Only the central portion of the blastoderm develops into the embryo—all the rest developing into the four extraembryonic membranes which will be described later.

Variations in the Method of Mesoderm Formation

The presence of large amounts of yolk modifies the method of mesoderm formation as well as the method of cleavage. The method in the embryonic chicken has been extensively studied as an example of this modified form of mesoderm formation. A mass of cells forms between the endoderm and ectoderm from the primitive streak and spreads out laterally. This is the mesoderm. Later a space develops on each side by a splitting of this cell mass into two parts. These spaces later fuse and produce the coelom. The coeloms produced in this way are identical in appearance with those produced in the manner described for Amphioxus.
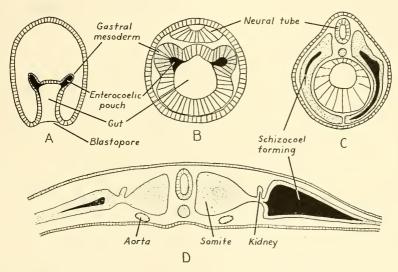
Fig. 33.5. Variations in method of coelom formation. (A) Starfish and (B) Amphioxus represent the enterocoelic method. (C) Amphibian and (D) bird and mammal represent the schizocoelic method. The coelom is shown in black.

The further development of the mesoderm is very important, because this layer forms by far the largest number of organs in the body. The mesoderm gradually separates into three regions, each of which develops many important parts of the growing animal. These are: the dorsal mesoderm, the intermediate mesoderm, and the ventral mesoderm. The dorsal mesoderm forms the **somites,** which function in muscle and skeleton formation. The intermediate layer gives rise to the kidneys. The ventral portion splits into the **splanchnic mesoderm** which fuses to the digestive tract and the **somatic mesoderm** which lines the body

cavity. These layers come together both above and below the digestive tube forming the mesenteries which hold these organs in place.

Formation of the Organ Systems

Brain and Spinal Cord. The following descriptions are based largely on the embryology of the frog, since this embryo is large and easily seen and it is not covered by a shell or extraembryonic membranes. The early stages of the embryo are round or nearly so, but as development proceeds the embryo becomes elongated in an anterior-posterior direction. At the same time the ectodermal cells on the dorsal surface divide rapidly and form a plate of cells known as the **neural plate.** The sides of this plate rise up and form a pair of **neural folds** leaving a depression between them, the **neural groove.** The folds soon close and form a
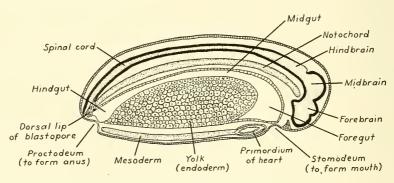
Fig. 33.6. Longitudinal section through a typical vertebrate embryo showing the method of formation of some of the body organs.

hollow **neural tube.** The anterior end of this tube is destined to form the brain. It gradually becomes constricted so as to form the three main parts, the **forebrain,** the **midbrain,** and the **hindbrain.** The posterior portion of the tube makes the spinal cord.

Alimentary Canal. The alimentary tract develops from the archenteron or primitive gut. When the neural groove closes over, the blastopore is temporarily covered. A posterior invagination, however, forms where the ectoderm and endoderm at first fuse and then perforate and form the anus. This invagination is known as the **proctodeum.** Occasionally this opening fails to form during embryological development and a surgeon must correct this mistake of nature. At the anterior end of the embryo, the opening for the mouth is produced by the ectoderm and endoderm fusing and forming the **stomodeum.** As the opening for

the mouth is formed, some of the ectoderm turns in for a short distance and forms the enamel organs which produce the teeth.

Meanwhile the primitive gut has divided into three regions: **foregut, midgut,** and **hindgut.** The foregut develops into the pharynx, esophagus, and stomach; the midgut into the small intestine; and the hindgut into the large intestine. The liver and pancreas are outgrowths from the foregut and remain attached to it by their ducts. As the digestive tube develops, it becomes attached to the inner layer of the mesoderm and this forms the outer layers of the alimentary canal. Thus, the final digestive tube is lined on the inside with endoderm and on the outside by mesoderm.
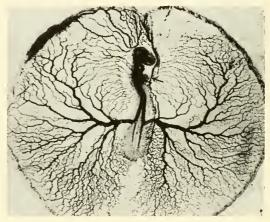
The Respiratory System. This system is primarily of endodermal origin. In the frog, which respires by gills in the larval stage, a series of endodermal evaginations from the pharynx meet a series of ectodermal furrows, and the two sets fuse to form **gill clefts.** In land animals, these same pharyngeal evaginations occur in the embryo, but no gills develop in connection with them. They are transient structures which soon disappear, except the first one which sends off a pouch which develops into the middle ear and Eustachian tube.

Later in embryonic development a ventral outpocketing takes place on the posterior floor of the pharynx. This pocket divides almost immediately and forms the two lung buds. The original opening forms the glottis which leads to the larynx. As the lung buds grow back into the thorax, an elongated tube, the trachea, is formed in most chordates and this branches to form the two bronchial tubes. In the frog the trachea is lacking, and the bronchial tubes come off directly from the larynx. As in the digestive system, the mesoderm covers the developing lungs and, thus, they are composed of two germ layers, endoderm and mesoderm.

The Skin and Its Outgrowths. The skin consists of two layers: the **epidermis** which develops from the original ectodermal layer, and the **dermis** which is mesodermal in origin. In the frog, a series of oval glands develop from the epidermal layer which helps keep the skin moist by their mucous secretions. In land vertebrates, the horny scales, nails, claws, hoofs, feathers, and hair are ectodermal outgrowths of the epidermis. The sweat glands and oil glands at the base of each hair are also ectodermal ingrowths from the epidermis.

The Circulatory System. Because the frog embryo is opaque the development of the heart and blood vessels can be more easily demonstrated in the thin, transparent embryo of the chick. This system, which is of mesodermal origin, develops very early and is the first system to become functional. Almost immediately it begins to move food to the

growing parts and to remove the wastes. Within 41 hours after the egg of a chicken begins incubation, a functional circulatory system will have developed with blood vessels containing blood corpuscles and a beating heart in the center of the system. If we open an egg which has been incubated about 48 hours we can see the flattened embryo on the upper side of the yolk mass. This embryo can be cut off with a sharp pair of scissors and floated on water in a watch glass. When viewed under a low powered microscope the heart can be seen pumping blood forward to the gill clefts and even the tiny blood corpuscles can be seen pulsing through the vessels. It is also possible to see the capillaries connecting the arteries and the veins. At first the heart is a simple tube, but it

Courtesy General Biological Supply House

Fig. 33.7. A 48-hour chick embryo showing the advanced state of development of the blood vessels and the heart. Since food and oxygen are brought in by the blood, the circulatory system develops very early in embryology. The vessels have been injected to make them show more clearly.

later becomes divided into an auricle and a ventricle. In the fish the heart remains in this condition, but in the frog a septum divides the auricle into right and left chambers. In the birds and mammals the ventricle as well as the auricle is divided into two chambers.

The Skeletal System. This system also originates from the mesoderm. The inner portion of each somite develops a region known as the **sclerotome** which breaks up into a mass of cells that migrate in and around the spinal cord and notochord and there form the vertebrae. Some of these wandering cells, known as **mesenchymal tissue,** also migrate into the developing limb buds and form the bones of the arms and legs. There are two types of bone according to their method of origin. **Membrane bones,** which are found only in the head region,

originate as membranes close to the epidermis. These membranes gradually sink deeper into the head region and ossify directly. These form the bones of the top of the head, the face, and the jaws. **Cartilage bones,** which make up the rest of the bones of the body, are laid down first as cartilages. These have very nearly the shape of the future bones. As development proceeds, calcium salts are deposited in ossification centers and the cartilage is replaced by bone. In the long bones the ossification centers are in the middle of the shaft and in the heads at either end. As long as these three centers of bone formation are separated by a layer of cartilage, the bones can continue to grow in length. Sometime between the ages of sixteen and twenty-one years of age most of these centers fuse and growth in height can no longer take place. X-rays can show the exact time when growth stops because these cartilage areas show plainly on x-ray films. At the time of birth the bones of the skull are only partially ossified and the head of the infant is bent to conform to the narrow birth canal in the pelvis of its mother. A baby is born with soft spots in its skull where the membranes have not finished ossification.

The Muscular System. Muscles make up about 40 per cent of a person's body by weight, which is more than any other single system. Practically all of the muscles are derived from the mesoderm (the muscles of the pupil of the eye and the muscles which cause the hair to stand on end are ectodermal). As we learned in Chapter 22, there are three kinds of muscles and each is formed somewhat differently.

Striated or **skeletal muscle** arises chiefly from the somites that are such a conspicuous feature of the early embryo. The main part of each somite is the myotome which gradually enlarges to form the muscles of the body wall, both the back muscles and the ventral muscles. In the frog the original myotomes can be observed in many of the muscles especially in the rectus abdominis of the abdomen. Greek sculptors, with their remarkable abilities to depict the human form, carved athletes with the same lines across the abdominal region, a feature which is rarely visible externally in human beings. The skeletal muscles of the arms and legs of the frog are formed from the same mass of mesenchymal cells which forms the bones.

Smooth muscles of the digestive tract are formed from the wandering mesenchymal tissue which migrates between the endoderm of the gut and the splanchnic mesoderm of the coelom. The cells gradually elongate and form the spindle-shaped cells that bring about peristaltic movements. Similar smooth muscles form around the blood vessels, the excretory ducts, and the urogenital ducts.

Cardiac muscle develops only in the heart from the splanchnic mesoderm which forms the main layer of the developing auricles and ventricles. This muscle becomes striated, and each fiber connects with other fibers, thus forming a continuous network.

Urogenital System. The **kidneys** originate in a pair of longitudinal folds of mesoderm which form from the **nephrotome** or intermediate plate of mesoderm. From this plate there arises a series of tubules which at first open into the coelom by ciliated funnels. Actually, there are three different kidneys formed in the evolution of vertebrates, and all of these are formed in the embryos of higher vertebrates. In the frog the head kidney or **pronephros** arises first in the anterior end of the coelom and functions for several weeks in the frog tadpole. It is followed by the **mesonephros** or midkidney which gradually enlarges and takes over the excretory function when the tadpole metamorphoses and forms a frog. At this time the pronephros degenerates and disappears. In higher animals including man, the hind kidney or **metanephros** is formed from the posterior end of the nephrotome and replaces the mesonephros. The latter does not disappear completely, but leaves some important vestiges behind in the male, namely the epididymis and vasa efferentia.

The gonads arise as **genital ridges** on the dorsal side of the body cavity, apparently from the coelomic epithelium. Since their origin is exactly the same in the male as in the female, the sex of an embryo cannot at first be determined. In this genital ridge there soon appear large round cells, the **primitive germ cells**. The **oviduct** appears in both sexes as a fold of the coelomic epithelium and is quite separate from the sperm duct. The latter develops from the mesonephric duct which at first carries only urine. In mammals the gonads gradually differentiate into ovaries or testes. If testes develop they then migrate posteriorly. In man the first difference in the sexes is not visible until the end of the seventh week. A pair of pockets from the coelom forms in most mammals at the posterior end of the body into which the testes descend shortly before birth—the ovaries remain in the body cavity.

The **external genital organs** also follow parallel lines of development with similar structures being developed in both sexes until the end of the second month in the human embryo. At first there is present only a **urogenital slit** surrounded by the **labioscrotal folds** and a **genital tubercle** at the anterior end. As development proceeds in the male, the genital tubercle greatly enlarges and forms the penis and the folds close to form the scrotum. In the female, the tubercle becomes the clitoris and the folds form the labia, or lips of the urogenital region.

In rare instances embryological abnormalities occur in the development of the external genitalia which result in intermediate conditions. The testes may not descend into the scrotal folds, the lips of the urogenital orifice may not fuse, and the genital tubercle may remain small. Such a child may be a male, but even a good physician may mistake the
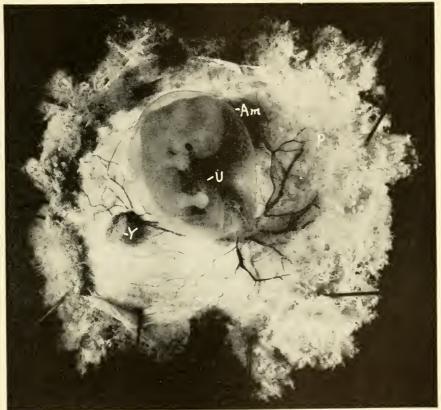
FIG. 33.8.   A human embryo 42 days of age with its connecting membranes.   Note the placenta which has been cut open to expose the embryo, the amnion containing the amniotic fluid in which the embryo floats, the umbilical cord which attaches the embryo to the placenta, and the rudimentary yolk sac.   Compare with the 32-day embryo shown in Fig. 21.1.

sex.   The opposite condition occurs when a female has a greatly enlarged clitoris accompanied by a closure of the labial folds which form what can be mistaken for a scrotum.   Internally there will probably be a well developed vagina and uterus.   Surgery can usually restore the proper sexual characteristics and heavy doses of the correct sex hormone will

usually bring about secondary sex changes which will stimulate the growth of the appropriate organs and also restore the correct physiological conditions for that sex.

The Embryonic Membranes.   Three of these membranes first appear in the reptiles and play a vital part in the life of the embryo within the shell.   The most primitive of the extraembryonic membranes is the **yolk sac** which appears in the fish embryos.   This is a living membrane, containing a network of blood vessels which carry food from the egg to the developing embryo by means of the vitelline arteries and veins. Curiously, this sac develops in mammals as an empty cavity, since the tiny egg of this class contains little or no yolk.   A vestige of this sac may persist in adults as a tiny projection on the small intestine.
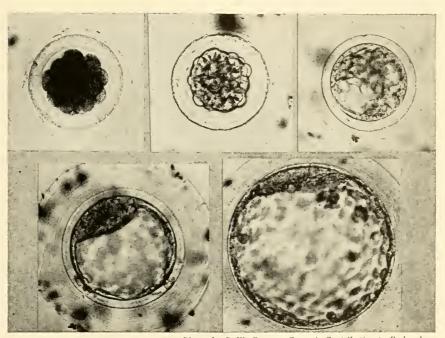
The second membrane, the **amnion,** is formed around the embryo of land vertebrates and becomes filled with amniotic fluid in which the embryo floats.   Thus land vertebrates have created an aquatic environment for their offspring which supports and protects the delicate parts of the embryo during development.   This gives excellent protection from pressure or blows, since according to a law of physics, force is distributed equally in all directions by a liquid.

The third membrane, the **allantois,** is formed as an outpocketing of the hindgut of the embryo anterior to the proctodeum.   In reptiles and birds, this membrane grows around the amnion and yolk sac in the space formed by the chorion, where it acts as an embryonic lung giving off carbon dioxide through the shell and absorbing oxygen.   In mammals the allantois forms the placenta by coming into intimate contact with the maternal uterus.   The allantoic blood vessels become the umbilical arteries and veins which reach the growing embryo through the long umbilical cord.   In human beings the endodermal component of the allantois is poorly developed, but the blood vessels are still the all-important link between the embryo and the mother.   The blood of the mother does not enter the embryo, but food and oxygen diffuse through the membranes of the placenta into the blood vessels and the wastes pass out the same way.

A fourth membrane, the **chorion,** is a very thin, unimportant membrane that lies next to the shell in birds and reptiles.   It is formed more or less by accident from the outer layer of the amniotic folds when they come together and fuse over the embryo.   In human beings the chorion is more important since, in the very young stage, it is the layer which bores its way into the uterus and absorbs the first nourishment before the allantoic blood vessels develop.   Thus, the placenta is formed in part from the chorion as well as from the allantois.

Early Embryogenesis of the Mammals

In the mammals special problems in embryonic development arise, and there are certain differences in the early stages. The mammal egg is small, and there is a small amount of yolk. The cleavage of the zygote is equal and total in the early stages, and a mass of cells of about equal size is formed. As divisions continue this mass forms an outer

Photos by P. W. Gregory, Carnegie Contribution to Embryology

FIG. 33.9. Early embryology of a mammal. These photomicrographs of living rabbit embryos are very much like similar stages in human development. The upper row shows a morula 55 hours after coitus; morula 72 hours after coitus; beginning of blastula formation 77 hours after coitus. The lower row shows a fully formed blastula with blastoderm near the top and the blastodermic vesicle filling the center of the ball at 90 hours. Also, a more advanced blastula at 92 hours.

layer, the **trophoblast layer,** and an **inner cell mass.** This entire body is known as the **blastodermic vesicle.** The embryo and the extraembryonic membranes develop from the inner cell mass. The trophoblast layer contributes to the formation of the chorion in combination with certain mesodermal cells which come to underlie it. From this point on the mammals show no great peculiarities in the development of their organs in comparison with the other chordates.

Experimental Embryology

In recent years there has been some very important work performed on early embryos by means of delicate microdissection instruments. Small bits of tissue have been transplanted from one part of the embryo to other parts of the same or different embryos. The growth and differentiation of these transplants have gone a long way toward the explanation of cellular development.

In a frog or salamander embryo, if a portion of the dorsal lip of the blastopore is excised from one embryo and transplanted to the ventral region of another embryo, two sets of organs will be formed. The transplanted blastopore tissue acts as an **organizer** and forms another neural tube, notochord, a double set of somites, and an archenteron at the same time as the normal blastopore of the embryo forms the regular set.

This power of induction by the cells of the dorsal lip region is due to chemical substances that diffuse into the surrounding cells. This tissue may be killed by boiling, freezing, or by chemicals without destroying its power to organize a set of tissues when grafted to a young embryo in the early gastrula stage.

In the very early gastrula when the dorsal lip of the blastopore has just begun to form, experiments have shown that the various germ layers are still undifferentiated. If a piece of tissue from the region of the future spinal cord is grafted to the region of future skin, the piece develops into ordinary skin and the skin grafted to the spinal cord region develops into the spinal cord. A little later, however, when the embryo has come under the influence of the organizer center during gastrulation, the same experiment yields exactly opposite results. The spinal cord tissue grafted to the belly region develops a tiny piece of spinal cord, and the skin grafted into the spinal cord region develops a piece of skin in the middle of the spinal cord. Even though all the cells still contain a full supply of genes, changes have taken place in the cytoplasm which restrict these cells to the formation of certain organs. Hans Spemann, the German embryologist who made these important studies, was awarded the Nobel Prize in medicine for explaining the mechanism of embryological specialization which had mystified biologists for centuries. Spemann further showed that the original organizer actually started a chain of organizers which continued the differentiation of organ after organ. For example, the brain forms the optic vesicle which in turn stimulates the adjacent ectoderm to form a lens. Such an optic vesicle, when inserted under the skin on the side of the body, will organize the overlying ectoderm into a lens.

When an undifferentiated limb bud, which is just a thin patch of mesoderm, is grafted onto a position midway between the front and hind limb positions on a salamander embryo, it will usually develop into a nearly perfect limb. It will acquire nerves from the adjacent segments of the spinal cord, but will be devoid of adaptive function because it does not obtain the proper reflex connections in the spinal cord. Even a small part of a limb bud is capable of producing a complete limb as can be shown by grafting the anterior half of the bud to one place and the posterior half to another location. In this experiment two complete limbs develop from one limb bud. Evidently, the cells in the half bud are able to restore and reorganize the missing parts of the other half bud—in other words, the cells have become bud-forming cells and are capable of forming any part of the bud. We call this a **restitution system.**

Salamanders have cells scattered through their bodies which retain most of their primitive characteristics and are capable of regenerating limbs even in the adult stages. Even in man there are connective tissue cells which form the scar tissue that closes wounds. The skin also regenerates rapidly. One theory of cancer holds that these cells, which are so important in cases of injury, get out of control and begin dividing wildly, forming parasitic tissue.

In summary, it is clear that since all the cells of a developing embryo have the same genes, some mechanism must appear that will cause these cells to develop into different tissues and organs. This is believed to be due to some chemical substance or substances that become concentrated in the dorsal lip of the blastopore. Before the action of this structure during gastrulation, all of the cells of the embryo are equally potent in producing any part of the embryo, but after the action of this organizer the cells have become so modified that they can produce only particular organs. Although embryonic differentiation is due to chemical changes in the cytoplasm, experiments have shown that the genes in the chromosomes play an important part in determining the type and quality of various structures as they form.

REVIEW QUESTIONS

1. Describe the main types of cleavage in the chordates.
2. Describe the different methods of formation of the blastula and the gastrula.
3. How is the mesoderm derived and the coelom formed in the different chordates?
4. What systems arise chiefly from the endoderm, mesoderm, ectoderm?
5. Describe the embryonic development of the nervous system.
6. Describe the embryonic development of the respiratory system.
7. Name the outgrowths of the skin and give the germ layers from which each is derived.

8. Tell how the three types of muscles originate.

9. Tell how membrane and cartilage bones originate.

10. Describe the formation of the three kinds of kidneys.

11. Discuss the abnormalities that bring about mixed sex characteristics.

12. The sex of human embryos cannot be determined until after they are about two months of age. Why is this?

13. Describe the origin and function of the four embryonic membranes of the land vertebrates.

14. How does the early embryonic development of a mammal differ from that of Amphioxus; the frog?

15. Discuss the importance of the organizer in the development of embryos.

16. What is the role of the genes in relation to organizers in the development of the embryo?

34

The Changing World of Life
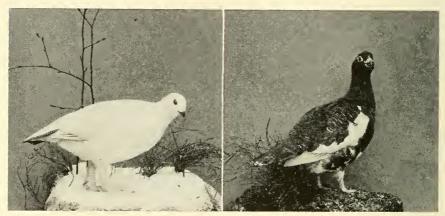
It has been said that the only invariable law of nature is variation. Everything in the universe seems to be subject to change. Astronomers tell us that the planets, the stars, and the nebulae are constantly undergoing changes in their relative positions, their illumination, and other characteristics. Geological studies show that the face of the earth has been greatly altered in the past and is now undergoing changes that will, in time, make our present-day maps of the continents obsolete. Fossils of deep-sea forms of life found hundreds of miles from present-day oceans enable us to trace the presence of prehistoric seas that once existed where some of our great cities now stand. Paleontology and geology show the great climatic changes that have occurred in the past. Fossils of tropical plants indicate that the United States at one time had a tropical climate, while geological studies show that huge glaciers have covered a great part of our country at other times. The social sciences show that there have been great changes in the social, political, and economic relationships of the people of the earth.

With such cosmic, geographical, climatic, and social evolution established, it would indeed be strange if there were not corresponding biological changes to keep pace with a constantly changing environment. Studies in almost all of the phases of zoology indicate that extensive changes in animal life have taken place in the past, are now taking place, and will continue to take place as long as animal life continues to exist. In fact, no species of animal is able to exist for long without such changes. The passenger pigeon, the dodo bird, and the dinosaurs are but a few of the many species of animals that have become extinct because they could not change fast enough to accommodate themselves to a changing environment.

Natural Selection

As has been brought out repeatedly in the course of our study of zoology, life is an adaptable thing. Individual adaptations and adjustments are constantly taking place as animals respond to the environment in which they live. These have no evolutionary significance, be-

cause they are not passed on to the offspring. Through the rigorous method of natural selection, however, there is an adaptation of the species, and these adaptations are inherited. This is the main force of evolution. Briefly, natural selection involves the overproduction of off- spring with the destruction by the forces of nature of those most poorly adapted to the environment. This is possible because of the natural variation that exists among living things due to the variations of the genes, even among offspring of the same parents. It stands to reason that whenever there is a difference among living things it is almost cer- tain that there will be some that will be better fitted for the particular

Fig. 34.1. Adaptation to changing seasonal environment. The Willow Ptarmigan has feather changes which make it blend with its environment in the different seasons of the year.

conditions under which these organisms live than others. In the long run, the best adapted will survive to reproduce and transmit their de- sirable genes to the future generations, while the undesirable genes would be eliminated along with the bodies of their carriers. This may seem like a somewhat wasteful and cruel method, but that is the way it is and no living things can escape the relentless force of natural selection.

The degree of selection varies considerably according to the number of young produced; those animals that do not give care to their young must make up for it by producing more than those that give a high degree of protection. Since more are destroyed in the first case, the degree of selection is greater when large numbers are produced and left to shift for themselves from the first.

A mature female bullfrog will lay about 15,000 eggs per year and, on the average, will reproduce about five years. If all of these hatched

and grew to adult size the earth would be covered with bullfrogs in several generations. Most of the eggs hatch, but the tadpoles and young frogs furnish food for fish, snakes, birds, mammals, and even frogs, including their father and mother. On the average, about two out of the entire group will survive to reach the adult stage and reproduce. These two, however, will be a highly selected pair; there has been no chance elimination that has left these two alone from the great host of
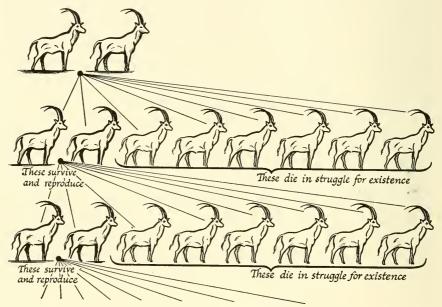
Photo by Winchester

FIG. 34.2. One out of the 37,500. This puffed up bullfrog has good reason to be proud. He alone has survived while about 37,499 of his brothers and sisters perished in the rigorous process of natural selection. In order to have survived this great slaughter, this frog must have many desirable characteristics which he can pass on to future generations.

their brothers and sisters. A fish catching a tadpole would catch the one that swam the slowest, that was most conspicuously colored, that was the slowest to detect approaching danger. This would leave the fast swimmers, the protectively colored, and the alert tadpoles alive to continue the struggle for existence. When food became scarce, those tadpoles that could detect its presence and get to it first lived, while their less sensitive and aggressive brothers and sisters starved. When they changed into young frogs and crawled up out of the water, those that learned to jump first reached the safety of the water, leaving the slower and more curious behind to be eaten by birds. Then, there are fungus

diseases that claim a toll of the more susceptible ones, leaving those highly resistant to such infections.

When the bullfrogs attain sexual maturity three or four years after hatching, they represent a highly select group. The many characteristics that these frogs possess that enabled them to survive while their brothers and sisters perished by the thousands all around them are largely hereditary. Therefore, the next generation of bullfrogs will be better able to withstand all these unfavorable environmental conditions.

These survive and reproduce   *These die in struggle for existence*

These survive and reproduce   *These die in struggle for existence*

From *Genetics*, Winchester, Houghton Mifflin

FIG. 34.3. The concept of natural selection as proposed by Charles Darwin. A pair of African antelopes produce about eight offspring, on the average, before they die. An average of only two of these survive in the struggle for existence. This is repeated each generation, thus creating a constant selection for those best suited to the environment.

If this is true, it may seem that a greater proportion of them should survive the second generation, still more the third, and so on. It is not this way, however, for it must be remembered that the frogs are not the only animals undergoing natural selection. All the fish, the birds, the reptiles, and even the fungus parasites are developing new and better ways of killing tadpoles and little frogs through this same rigorous process. It is now clearly evident why the statement was made at the first of the chapter that no animals can remain as they are and continue to exist. Their enemies are not standing still; they are constantly de-

veloping new and better ways of destruction and, unless there is a constant improvement of methods of resistance, extinction is a certainty.

At the opposite end of the scale we find the large, slow-breeding animals that produce a much smaller number of offspring, but give protection to those that are produced to reduce the loss during the early stages of life. One of the best illustrations of such slow breeding animals is the elephant. The gestation period of elephants is about two full years, so the young elephant has the protection of its huge mother's body for the first two years of its life, and it is large enough when born to be able to protect itself very well. However, even then, the mother shows a solicitude for her baby that is unexcelled in the entire animal kingdom, and woe betide any creature that is rash enough to molest a young elephant in the presence of its mother, and she is always near enough to come running at the slightest squeal from her baby. As if this were not enough, one of the other female elephants in the herd that does not have a baby of her own will aid in the protection of this one. This second female is called the "auntie," and between the two there isn't much chance of harm coming to the precious infant. This protection continues for years until the young elephant is large enough to hold its own among other members of the herd.

It will be about ten years before the mother will be able to give birth to a second baby under such a system. However, because of the long life of elephants a single female will have seven or eight offspring during her lifetime. On the average, only two of these will live, so there is natural selection and elimination of the least fit among the elephants just as there is among the bullfrogs.

Among human beings, natural selection works to eliminate the unfit just as surely as it does among the other forms of life. By means of medical science and social welfare agencies we have been able to reduce the number eliminated in the highly civilized countries, but it is impossible to save those least adapted to our environment. We have balanced this with a reduced birth rate, so that there is not a great population increase in these countries. In the less civilized countries, however, the birth rate and death rate continue at the same high level found in other forms of animal life.

Sexual Selection

This is a phase of selection that is of great importance in maintaining the vigor of a race. It does not work by the complete extermination of the least fit, but by eliminating reproduction of the least fit. It is most effective among the males because most of the females manage

to get fertilized anyway, but there may be a great struggle among the males in the battles for possession of the females.

The seals offer a good illustration of such battles. Seals will be found in groups consisting of a huge bull and a harem of quite a number of cows together with the young seals, or calves. The skin of the bull will probably show many scars as relics of furious battles with other males for the possession of the females. When the young male seals of the group become old enough to begin to take an interest in the op-

Photo by Winchester

FIG. 34.4. Sexual selection in the fur seal. The huge bull in the upper left has taken possession of a large group of females through many victorious battles with other males. A "bachelor" male looks on at the extreme right perhaps to battle for the possession of the females.

posite sex they are run off by the bull. They must live a solitary existence until they become strong enough to capture some females of their own in combat and start a harem. Since each harem may consist of a large number of females, it is readily apparent that there will be some males that will not succeed in the struggle. These will be the weakest of the group and will thus fail to perpetuate the genes that may have been responsible for their weakness.

Even though there may be no such definitely established harem, the process will be just as effective when the association is temporary. The

bull moose are noted for their ferocious battles for possession of the females during the reproductive season. The huge antlers that characterize the males are used primarily for fighting other males and are shed shortly after the reproductive period. Through such battles, a strong, vigorous bull will be able to mate with many females and transmit genes which will tend to strengthen the entire species.

The honeybees, as studied in Chapter 16, show an interesting variation where the males do not fight one another, but engage in a sort of endurance contest as they fly in the air in pursuit of the virgin queen.
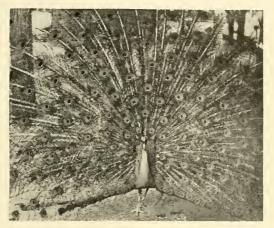
Photo by Winchester

Fig. 34.5. A peacock spreading. Sexual selection might be one explanation for the beautiful feather pattern of the male as compared to the rather drab colored female.
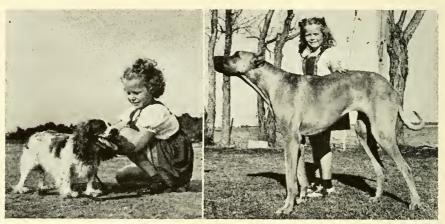
It is reasonable to assume that one of the strongest drones of the group will outlast the others and mate with the queen and become the father of many thousands of workers.

Among some birds, there is an elaborate courtship with the males strutting and displaying themselves to their best advantage before the females. In this case, it seems that the females exert some selection and pick the male that has the greatest appeal. This does not necessarily mean that they will pick the strongest, so this method might not be of significance in the preservation of the race, but may account for some of the beautiful feather patterns and shapes among many male birds. The females, on the other hand, usually remain rather drab in comparison, for they would be too easily visible when sitting on their nest with brilliant plumage, and natural selection keeps them protectively colored.

Artificial Selection

What nature does through natural and sexual selection, man can do through artificial selection of animals in which he can control their breeding. The results may not be for the best welfare of the animal, but may make the animal more like man would like for it to be.

Compare a slim, vigorous, aggressive, razorback hog, which is somewhat like the ancestral hog, with one of the modern breeds, such as a Poland China. It is easy to see the effects of artificial selection. By selecting for breeding those hogs that were the best pork producers, man has developed an ideal pork producing breed, but this has not been

Photos by Winchester

FIG. 34.6. Results of artificial selection. Through many generations of selection, dogs of great variation in size, appearance, and temperament have been produced. This little girl has to kneel to pet her cocker spaniel; but the great dane is almost big enough for her to ride.

for the best interest of the hogs. Through such selection the Poland China is now almost completely dependent on man for its existence and probably could not survive if turned loose in the woods to shift for itself.

Normally, mammals only produce milk during the suckling period and then only enough to supply the needs of their offspring, but through selection man has developed breeds of cows and goats that produce milk in large quantities most of their lives so that we can use it. The same principle applies to egg laying in chickens.

A study of the many breeds of dogs shows us to what extremes artificial selection may go. A great dane and a cocker spaniel are different in size, body build, length of hair, disposition, and many other charac-

teristics, yet they both had their origin as a wild dog that became domesticated in the distant past.

There seems to be almost no limit to the extent of changes that may be induced through artificial selection. Fig. 34.7 shows the effects of three generations of selection on size of eggs in poultry. Artificial selec-
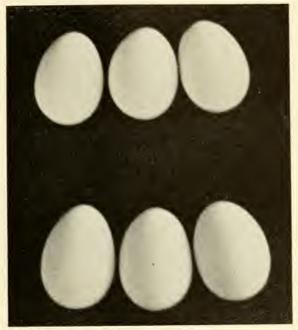
Photo by Winchester

FIG. 34.7. Artificial selection for egg size. The eggs at the top are the average size laid by a flock of chickens raised at Mt. Hope Farm, Williamstown, Mass. After three generations, in which only the largest eggs were selected for incubation, the third-generation hens laid eggs noticeably larger. The eggs at the bottom are examples of the average size of such eggs.

tion can go faster than natural selection because there can be a more absolute control of the breeding individuals, yet the principles involved are the same.

Mutation and Selection

If there were no way in which genes could be changed, selection would necessarily be limited. An animal could advance so far in one direction, but when the genes available in the species were exhausted, advance would have to stop. There is a means of gene change, however, that makes advance unlimited. This method is called mutation.

Genes are known to undergo a sudden change at times that causes an entirely different expression of the character which they control. For instance, the gene for white coat color in guinea pigs may suddenly mutate to black and a black guinea pig will be born in a race of pure white ones. This black gene will continue to show in the offspring of this black guinea pig, showing that the mutant gene is stable and remains in its new condition through the generations. Such gene changes offer new characteristics for selection, whether it be natural, sexual, or artificial.

Courtesy Walter Landauer, Storrs Exp. Sta.

FIG. 34.8. Mutation in domestic sheep. The individual on the left is an Ancon sheep that arose by mutation from sheep like the one on the right. Note the shorter legs on the Ancon.

Of course, all mutations will not be desirable changes; in fact, many of them will be definitely undesirable; but some will be of advantage, and these may be selected for leaving the disadvantageous ones to be eliminated.

Under natural conditions, mutations occur at a rather slow rate. For instance, Haldane has estimated that a single human gene will mutate naturally about once every 2,500,000 years, on the average. This rate may seem so small as to make it appear as if mutations could have little effect on evolution. However, when we consider the fact that there are about 20,000 genes in each cell of man's body and take 30 years as the average age of parents when children are born, we find that about one child out of every five will have received some sort of mutated gene. Many of these will be very minor in nature, but it is easy to see how such a rate of mutation can have important evolutionary significance.

We should not close this discussion of mutations without mentioning one of the most important phases of it—a phase which greatly concerns all of us in this atomic age. High energy radiations, such as X-rays, radium, and the neutron radiation from the products of atomic fission, can increase the rate of mutation. Since most mutations are likely to be harmful to the persons who express them, it is possible that mass exposure of large numbers of people to radiation from atomic or hydrogen bombs can result in harmful changes in the genes of heredity. (The amount of radiation received in routine X-ray pictures is too small to be of great consequence in this connection.) In natural and artificial selection the harmful mutations are gradually eliminated from a species, but in man we try to save all of those born regardless of any defects which may be present. An excessive number of mutations can thus weaken an entire race. All too often, we concentrate on the damage which may be done to individuals by the explosion of these new bombs, but we might well be concerned about their effects on the germ plasm which will carry on into the future.

Biological Evolution

The constant changing of living things which takes place as a result of mutations coupled with selection is known as biological or organic evolution as distinguished from cosmic, geographical, and other forms of evolution. That these changes have occurred in the past and are now occurring is a definitely established fact which anyone can verify who will take the trouble to investigate the evidence available. The full extent of these changes, however, is open to question and probably can never be settled absolutely, since the evidence is incomplete and of a circumstantial nature.

However, since life has existed on the earth for quite a few million years, it seems that evolution has been quite extensive. There was an unfortunate confusion of the facts and theories of evolution with religious issues at a time in the past that caused misunderstandings on the subject. Today, most thinking people realize that the exact method of creation of plant and animal life is a scientific and not a religious question. There is nothing in the evolutionary concept that could weaken one's religious belief. If we will free our minds of any prejudice in this connection and examine some of the evidences of evolution, we can gain some insight into the possible extent to which it has taken place.

Evidence from Embryology. A study of embryonic development of animals often gives us valuable information concerning the evolutionary relationships with other animals. The lamprey eel as an adult is quite

different from Amphioxus, and by studying only the adult type it might
be concluded that the two animals were not closely related. However,
as we learned in Chapter 25, the lamprey larva is so nearly like Am-
phioxus that the two were placed in the same subphylum until it became
known that the larval form changed into an adult that was already
placed in a different group. It would seem very unlikely that this simi-
larity is accidental; it would seem more plausible that the two had com-
mon ancestors, but have diverged in their development. The similarity
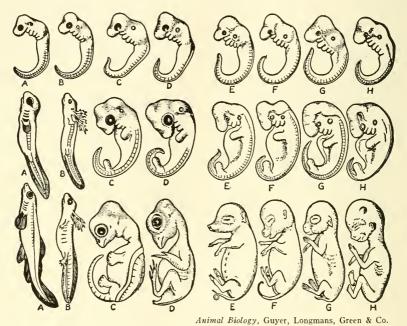
FIG. 34.9. A series of embryos of different animals at comparable stages of em-
bryonic development. Note the close similarity between all of the early embryos, with
some distinctions appearing in the middle row, and individual species characteristics
becoming distinct in the later stages shown in the bottom row. A, fish; B, salamander;
C, turtle; D, chicken; E, pig; F, calf; G, rabbit; H, man.
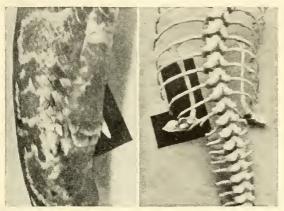
of the worm-like larvae of insects to the annelids would indicate a similar
connection.

The embryonic development of gill clefts among all the vertebrates,
as discussed in Chapter 21, seems to be significant. It is difficult to see
why the embryo of a snake should develop gill clefts, just as the embryo
of a fish, when the snake will never use gills, unless there is a relation-
ship between the two. The vertebrate heart, as studied in the same
chapter, has two chambers in the three aquatic classes, three in the
Amphibia, three with a partial partition in the ventricle in the reptiles,

and four in the birds and mammals. The embryos of the entire group first develop the two-chambered heart; if the adult has more, these two are properly divided during embryonic development and the adult has the correct number.

Such cases are so numerous and the implications so obvious that one who carefully studies embryology can hardly fail to see relationships between many different forms of life.

Evidence from Comparative Anatomy. A comparative study of the anatomy of different animals reveals structures whose presence can hardly be explained by anything besides evolutionary relationships.
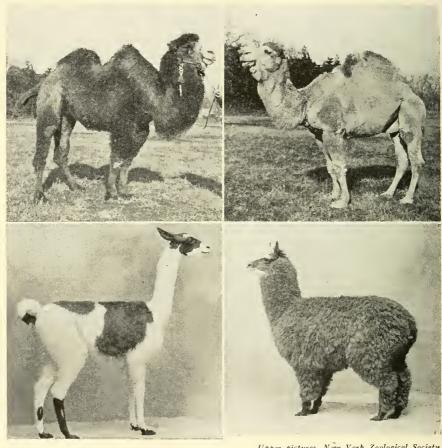
Photos by Winchester

FIG. 34.10. Vestigial legs of the python. Although most snakes show no sign of legs, there are some like the python that have vestiges of them. The photo on the left shows the vestigial legs on either side of the cloaca. On the right, the skeleton of the same region of the body shows that there is also a vestigial pelvic girdle to which the legs are attached.

The huge python snakes of Africa have vestigial legs projecting from their bodies on either side of the cloaca, and other snakes have internal vestiges of legs. The horse stands on the tip of one toe, yet rudiments of other toes may be found higher up on the leg. Birds have a third eyelid that moves across the eye from the anterior to close it; the mammals have this eyelid in a vestigial form, placed in next to the nose, but it is not large enough to close the eye. The appendix of man seems to be a vestige of an extension of the large intestine which is much larger and has an important digestive function in some animals. Some gifted persons can wiggle their ears with the small ear muscles, but they hear no better than the rest of us. On the other hand, these muscles are of importance in dogs, donkeys, rabbits, and other animals that turn their

ears to pick up sounds more efficiently. Thousands of such examples could be given to indicate relationships through anatomy.
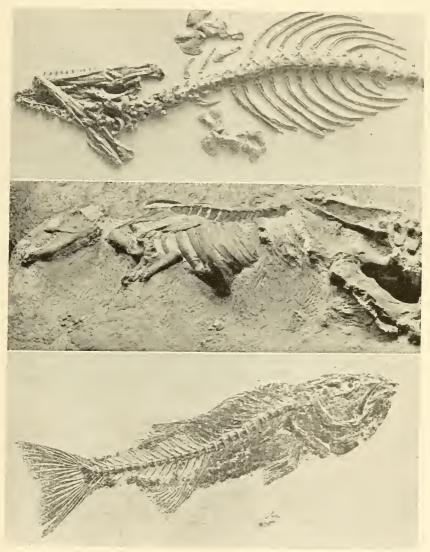
Evidence from Genetics. The ultimate basis for all evolutionary changes must be genetic in nature, for changes in living things must be inherited to have significance in altering the species. We have already learned how gene mutations coupled with selection can result in evolu-

Upper pictures, New York Zoological Society
Lower pictures, Chicago Natural History Museum

FIG. 34.11. Evolution in the camels. When animals of the same type migrate to varying environmental conditions, they tend to develop differences in accordance to the environment in which they live. The Bactrian camel at the upper left is found in Central Asia where cold weather is encountered and has developed long shaggy hair as a protection. The Dromedary or Arabian camel lives in desert regions and has developed broad pads on its feet to give it traction on the sand and pouches in its stomach to store water. The llama of South America at the lower left has followed another line of development. The alpaca at lower right has developed a heavy shaggy coat as a protection against the cold.

tion. Also, there can be changes in the chromosomes themselves. Stud-
ies of genetics have shown us ways in which evolution can take place.
High energy radiation not only increases the rate of mutation, but also

FIG. 34.12. Fossil remains enable us to trace the development of animal life in the
past. Top, a mosasaur that lived about 80 million years ago, found in Kansas. Center,
a ground sloth only partly excavated, found in Bolivia. It lived about a million years
ago. Bottom, a fossil fish that lived about 45 million years ago, found in the Green
River slate in Wyoming.

increases the rate of chromosome rearrangements which are an important part of evolution. By the use of radiation it is possible to speed up evolution, so to speak, and study these changes first hand. Then, by comparison of the chromosomes of closely related species it is possible to trace the probable course of changes which have occurred in the past. There is an interesting case to show how this happens in nature. A group of rabbits were taken to the island of Porto Santo during the fifteenth century. By the middle of the nineteenth century their descendants had accumulated so many genic and chromosomal changes that they were classified as a different species.
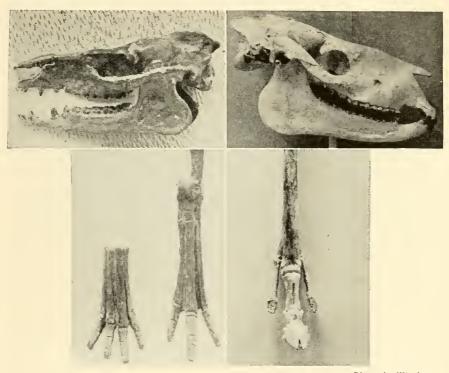
Photo by Winchester

FIG. 34.13. Mesophippus, primitive ancestor of the modern horse, that lived about 30 million years ago. These horses were about the size of a collie dog and had three toes on each foot. This is a reconstruction of three animals made after thorough study of fossil remains of these animals. It is located in the Chicago Natural History Museum.

Evidence from Zoogeography. Let us assume that a group of animals of the same kind are living in a temperate locality where there is an average amount of rainfall and conditions are not extreme in any form. They begin to spread out from this center to environments with varying conditions. One group migrates into a hot, dry, desert-like country; another goes north and meets more severe winter weather; another moves south and ends up in a hot, humid jungle; others remain where they are. Under such a variety of conditions, it is evident that natural selection would proceed along different lines. After a long

period of separation, the groups would certainly show differences from one another and the changes might even be so extensive that they would be classified as different species. This is what happened to the rabbits at Porto Santo, but since natural spread and adaptation of animals is slow, we usually have to study animals in their present environment and see how they differ from their ancestors in other localities.

Photos by Winchester

FIG. 34.14. Fossil remains of prehistoric ancestral horses. At left, small skull and front and hind feet of Eohippus, which lived on the earth about 35 million years ago. It was only the size of a fox terrier dog and had four toes on the front legs and three on the hind legs. At right, skull and foot of Mesohippus, which lived about 30 million years ago. It was about the size of a collie dog and had three toes on both front and hind feet, but the center toe was much larger than the other two.

The camels serve as a good illustration of adaptations to different environments. The one-humped Arabian camel has lived in the desert and is well adapted for such life. There are broad pads on its feet which give it traction in the sand, there are pouches in its stomach which store water, and extra food is stored in the hump. The two-humped Bactrian camel lives in more northerly regions and has developed long shaggy

hair which protects it from cold weather and its feet are hard for the rocky terrain in which it lives. There doesn't seem to be much doubt but that both of these arose from a common ancestor and through the centuries have become adapted to different environments. The South American llama seems to be another member of this group that migrated across to South America when there was a land bridge connecting the two continents. Living in the high altitudes, this animal developed a very shaggy coat, became smaller in size and changed in other ways that distinguish it today.

Evidence from Paleontology. According to the best paleontological evidence, life has existed on the earth about 1,000,000,000 years. This is not just a guess, but is based on accurate scientific determination of

Chas. R. Knight, Chicago Natural History Museum

FIG. 34.15. Mammoths and mastodon, prehistoric elephant-like animals. These restorations of extinct animals have been made through fossil remains and even some preserved specimens in the ice of Siberia. Through such studies, paleontology, it is possible to trace the course of evolution in the past.

the age of the lowest rock strata that contain remnants of living things. We have complete knowledge of animal life only as it has existed during the present and the comparatively recent past. Fortunately, we do have some record of prehistoric life in the form of fossils that have remained through the ages of time as a record of life as it once existed. There is no evidence of evolution more convincing than a study of these prehistoric forms in comparison to their descendants of today.

One of the most complete records of the past is found for the horse. The earliest remains of horses that have been found were about the size of a house cat with four functional toes on the front legs and three on the hind legs. In more recently deposited strata, remains have been found that were about the size of a small dog, with the same toe development. The next deposits reveal a horse about the size of a sheep, but with only three functional toes on all four feet. Later, they are found about the size of a Shetland pony, with three toes on each foot,

but the center toe is enlarged and the other two did not touch the ground. The most recent fossils show a horse about the size of those today and using only one toe, which was greatly enlarged. Similar progressive changes can also be observed in the length of the skull and the development of the teeth. Fig. 34.14 shows some of the changes that have been noted.

The development of many other animals has been worked out in a similar manner, but the horse offers the most complete series. The evolution of the elephant was worked out with the aid of complete preserved specimens in addition to fossils. A number of years ago, explorers in the frozen wastes of northern Siberia noticed their dogs eating something just under the snow. Investigation showed that it was the frozen body of a huge mammoth that lived about 20,000 years ago. This was a huge, hairy ancestor of our modern elephants that lived in temperate and cold climates. Since that time about fifty of these prehistoric animals, preserved by cold storage, have been found. As stated previously, it is even reported that there was a scientific banquet in London at which 20,000 year old mammoth steaks were served.

Evidence from Serology. Serology is one of the most recently developed studies which gives us evidence of evolution. The technique employed, in brief, is as follows. The liquid part of the blood, the serum, of a certain animal is separated from the blood cells and injected into some other animal, such as a rabbit. This causes the test animal to develop antibodies against certain protein components of this serum. This is the same sort of reaction which causes animals to develop antibodies against disease germs. The human body also sometimes develops antibodies against certain pollens which may be inhaled, and the condition known as hay fever results when this pollen reacts with the antibodies. Now, let us see how this sort of reaction helps in studies of evolution. Suppose the serum from domestic cattle is injected into a rabbit. If some of the serum from the rabbit is now mixed in a test tube with some of the serum from a domestic cow, there will be a precipitation and the mixture will become cloudy. This gives visual evidence of the reaction of the antibodies. Now, suppose we mix some of the serum from such a rabbit with the serum from the bison, or American buffalo. We would probably get some cloudiness, but not as much as in the first instance. This would indicate that there was some degree of relationship between these two species. If we now mixed some serum from this same rabbit with serum from an elk we might get a slight precipitation, but not as much as from the bison. This would indicate a more distant relationship. If mixed with the serum from a horse, there would probably be little or no precipitation.

Thus, serology gives us another valuable tool to help unravel the mysteries of biological evolution. The findings of serology, in general, have upheld the conclusions which have been drawn from the other fields which we have surveyed. The many evidences together show us that evolution of living things has occurred and is occurring without any question. They also indicate that this evolution has been very extensive in scope.

REVIEW QUESTIONS

1. Compare individual adaptation with species adaptation.
2. How is the number of offspring produced related to the rapidity of natural selection?
3. How is it that sexual selection may sometimes be beneficial and sometimes harmful to the race?
4. How does artificial selection compare with natural selection in its methods and results obtained?
5. What is the relation betwen mutation and natural selection?
6. Discuss the various evidences of evolution from different branches of biology.
7. We say that without mutation evolution would be very limited in scope. Explain.
8. Explain the technique of serological comparisons of two animals which appear closely related.

Glossary

This glossary has been prepared as an aid in expanding the scientific vocabulary of the biology student. All of the scientific words that are used in the book that might not be in the vocabulary of the college freshman are listed together with their pronunciation and meaning. For a fuller understanding of a word it is suggested that the student look the word up in the index and read about it more fully in the text.

The definitions given are in relation to the biological usage of the word.

Scientific names of animals and groups of animals are not included in the glossary. These, together with their derivations, may be found at the close of the chapters in which the animals are studied.

Pronunciations are given according to usage by competent biologists, such as is heard at national scientific gatherings. The simplified system of phonetics used for the vowels is as follows:

ă, as in ăm, căp.
ā, as in dāy, hāy.
à, as in wàs, àlone.
ä, as in äll, pälm.
ĕ, as in gĕt, rĕd.
ē, as in bē, thē.
ẽ, as in undẽr, dancẽr.

ĭ, as in bĭt, rĭd.
ī, as in bīte, rīde.
ŏ, as in hŏt, bŏb.
ô, as in hôrse, côrn.
ō, as in hōle, rōpe.
ŭ, as in cŭp, hŭrl.
ū, as in mūle, dūty.
û, as in ûrn, fûrl.

Ab- (ăb), prefix meaning "out of" or "away from".

Abdomen (ăb-dō'-mĕn or ab'-do-men), the region of the trunk posterior to the thorax.

Abductor (ăb-dŭk'-tẽr), refers to a muscle that draws an appendage away from the mid-line of the body.

Aboral (ăb'-ō-răl), the direction away from the mouth; in contrast or oral which refers to the mouth.

Abyssal (à-bĭs'-ăl), the bottom of the sea.

Acromegaly (ăk-rō-mĕg'-à-lĭ), disease caused by hypersecretion of the growth hormone of the pituitary gland after physical maturity.

Ad- (ăd), prefix meaning "to" or "towards".

Adductor (ăd-dŭk'-tẽr), refers to a muscle that draws an appendage toward the mid-line of the body.

Adrenal (ăd-rē'-nàl), pertaining to a pair of endocrine glands just above the kidneys.

Adrenalin (ăd-rĕn'-à-lĭn), hormone secreted by the medulla of the adrenal glands.

Allantois (à-lăn'-tŏĭz), an outgrowth of embryonic birds and reptiles that takes care of respiration through the shell.

Alveoli (ăl-vē′-ō-lī), small air sacs in the lungs.

Amoeboid (à-mē′-bŏĭd), pertaining to the method of locomotion by means of pseudopodia as is found in amoeba.

Amitosis (ā-mī-tō′-sĭs), cell division without the formation and division of chromosomes.

Amnion (ăm′-nĭ-ŏn), a membrane containing a fluid in which the embryo of reptiles, birds and mammals float.

Ampulla (ăm-pŭl′-à), a small membranous sac.

Analogous (à-năl′-ō-gŭs), referring to body parts of animals that have different embryonic and phylogenetic origins, but which have the same function.

Analogy (à-năl′-ō-jĭ), the relationship between body parts having different embryonic and phylogenetic origin, but with the same function.

Anaphase (ăn′-à-fāz), the third phase of mitosis.

Anatomy (à-năt′-ō-mĭ), a phase of biology dealing with gross structure; a subdivision of morphology.

Antenna (ăn-tĕn′-à), a sensitive "feeler" from the head of an animal.

Anus (ā′-nŭs), the posterior opening of the digestive tract.

Aorta (ā-ôr′-tà), the largest artery of vertebrates; it leads from the heart carrying blood to other arteries of the body.

Aquatic (à-kwăt′-ĭk), pertaining to the water.

Archenteron (ärk-ĕnt′-ēr-ŏn), the primitive intestine.

Atrium (ā′-trĭ-ŭm), a cavity.

Auricle (ô′-rĭ-kl), a chamber of the heart that receives blood coming to the heart.

Autonomic (ô-tō-nŏm′-ĭc), refers to a part of the nervous system that regulates the involuntary reactions of the body.

Autotomy (ô-tŏt-ō-mĭ), the throwing off of a limb or other body part, usually following an injury to that body part.

Biramous (bī-rā′-mŭs), possessing two branches.

Blastocoel (blăs′-tō-sēl), the cavity within the blastula.

Blastopore (blăs′-tō-pōr), the external opening of the early archenteron.

Blastula (blăs′-tū-là), the hollow-ball stage of embryology.

Bronchial (brŏng′-kĭ-àl), refers to tubes leading to the lungs.

Caecum (sē′-kūm), pl. caeca, a blind pocket-like pouch.

Calcareous (kăl-kār′-ē-ŭs), composed primarily of lime.

Capillary (kăp′-ĭ-lēr-ĭ), a tiny blood vessel that connects an artery with a vein.

Carapace (kăr′-à-pās), the hard covering of the cephalothorax of many crustaceans.

Cardiac (kär′-dĭ-ăk), refers to the heart.

Carotid (kà-rŏ′-tĭd), pertaining to the large arteries of the neck.

Carpal (kär′-păl), a wrist bone.

Cartilage (kär′-tĭ-lāj), an elastic animal tissue; usually precedes bone in the formation of the skeleton of chordates.

Caudal (kô′-dăl), pertaining to the tail.

Centrosome (sĕn′-trō-sōm), a body consisting of a central centriole with radiating astral rays found in the cytoplasm of most animal cells; forms the spindle figure for mitosis.

Cephalo- (sĕf′-à-lō), prefix referring to head.

Cerebellum (sĕr-ē-bĕl′-ŭm), a division of the brain of chordates.

Cerebrospinal (sĕr-ē′-brō-spī′-nàl), referring to the brain and spinal cord.

Cerebrum (sĕr'-ē-brŭm), a division of the brain of chordates.

Cervical (sûr'-vĭ-kål), pertaining to the neck.

Cheliped (kēl'-ĭ-pĕd), the large pincher of the crayfish, lobsters, and crabs.

Chitin (kī'-tĭn), a horny substance forming the outer covering of many Arthropoda; also forms internal structures in some Arthropoda and other forms of life.

Chloragogue (klō'-rå-gŏg), refers to the cells on the outside of the intestine of the earthworm.

Chlorophyll (klō'-rō-fĭl), the green coloring matter in plants; the material that manufactures food in plant cells.

Chorion (kō'-rĭ-ŏn), one of the embryonic membranes of higher vertebrates.

Choroid (kō'-rŏĭd), the middle, pigmented layer of the eye of vertebrates.

Chromosome (krō'-mō-sōm), heavily staining, rod-shaped body that is seen in mitosis; carries genes of heredity.

Chromatin (krō'-må-tin), material in the nucleus that is concerned with heredity; stains heavily; forms the chromosomes in mitosis.

Cilia (sĭl'-ĭ-å), tiny hair-like projections usually found in large numbers on certain cell surfaces.

Circum- (sĕr'-kŭm), prefix meaning around.

Clavicle (klăv'-ĭ-kl), the colar bone.

Clitellum (klĭ-tĕl'-ŭm), an enlarged ring around the earthworm; secretes the cocoon.

Clitoris (klĭ'-tô-rĭs), a small body of erectile tissue at the anterior portion of the external genitalia of the higher vertebrate females.

Cloaca (klō-ā'-kà), a posterior cavity found in many vertebrates that receives the waste food, the excretory waste, and the reproductive products and empties them all through one external opening.

Coccyx (kŏk'-sĭx), vestige of tail bones in man and apes.

Cochlea (kōk'-lē-à), the coiled structure of the inner ear containing the sensory endings of the auditory nerve.

Coeliac (sē'-lĭ-ăk), pertaining to the abdomen.

Coelom (sē'-lōm), the body cavity lying between the digestive tract and the body wall; it is lined with mesoderm.

Commensalism (kŏm-mĕn'-sål-ĭzm), an association between two living organisms in which one benefits, but the other is neither benefited nor harmed.

Conjugation (kŏn-jū-gā'-shŭn), a primitive form of sexual reproduction found in Paramecium.

Copulation (kŏp-ū-lā'-shŭn), sexual union involving the transference of sperm from one animal to another.

Coracoid (kôr'-à-kŏĭd), a bone in the pectoral girdle of the frog.

Cornea (kôr'-nē-à), the transparent outer layer at the front of the eye.

Corpus luteum (kôr'-pūs lūt'-ē-ŭm), hormone-producing body on the ovary of pregnant mammals.

Cortex (kôr'-tĕx), the outer portion of the cerebrum of chordates; the outer portion of the kidney; the outer portion of the adrenal gland.

Cortin (kôr'-tĭn), hormone secreted by the cortex of the adrenal glands.

Cretin (krē'-tĭn), an abnormal person, characterized by physical and mental retardation; may be caused by deficiency of thyroxin in early life.

Cutaneous (kū-tān'-ē-ŭs), pertaining to the skin.

Cyst (sĭst), a protective coating developed around the outside of an organism or a part of an organism.

Cytoplasm (sī'-tô-plăzm), cell material lying between the nucleus and the outer plasma membrane.

Dermal (dûr'-măl), pertaining to skin.

Diabetes (dī'-à-bē-tēz), disease caused by deficiency of insulin.

Diaphragm (dī'-à-frăm), a muscular partition separating the thoracic and abdominal cavities in mammals.

Diencephalon (dī-ĕn-sĕf'-à-lŏn), the second portion of the brain of vertebrates, often called the thalamus in man.

Dimorphism (dī-môr'-fĭzm), two forms within the same species.

Dinosaur (dī'-nō-sôr), extinct reptile that dominated the earth during the mesozoic era.

Diploblastic (dĭp-lō-blăs'-tĭk), having two germ layers in the body.

Diverticulum (dī-vĕr-tĭk'-ū-lŭm), pl. -la, a small intestinal branch as found in Planaria.

Duodenum (dū-ō-dē'-nŭm), the first loop of the small intestine in vertebrates.

Dysentery (dĭs'-ĕn-tĕr-ĭ), a disease of the colon characterized by diarrhea; one form caused by an Endamoeba.

Ecology (ē-kŏl'-ō-jĭ), a phase of biology dealing with the living organism in relation to its environment.

Ecto- (ĕk'-tō), prefix referring to outside.

Ectoderm (ĕk'-tō-dûrm), the outer germ layer of animal bodies.

Egestion (ē-jĕs'-chŭn), the elimination of indigestible food waste.

Elephantiasis (ĕl-ē-făn-tī'-à-sĭs), a disease involving great enlargement of various body parts.

Embryology (ĕm-brĭ-ŏl'-ō-jĭ), a phase of biology dealing with the development of the individual from its earliest beginning until it reaches the adult type.

Encyst (ĕn-sĭst'), the development of a cyst around the outside of an organism or part of an organism.

Endo- (ĕn'-dō), prefix referring to "inside".

Endocrine (ĕn'-dō-krĭn), pertaining to a series of glands in the bodies of higher animals whose secretions are spread over the body by blood and lymph rather than by ducts.

Endoderm (ĕn'-dō-dûrm), the inner germ layer of animal bodies.

Endopodite (ĕn-dŏp'-ō-dīt), the inner and main branch of a biramous appendage.

Enteric ĕn-tĕr'-ĭk), refers to the intestines.

Enterocoel (ĕn'-tĕr-ō-sēl), a body cavity formed by an outpocketing of the primitive gut or enteron.

Entomology (ĕn-tō-mŏl'-ō-jĭ), a study of insects.

Enzyme (ĕn'-zīm), a substance secreted by cells that has the power to produce chemical changes in some specific substance, such as changing starch to sugar.

Epipodite (ĕp-ĭp'-ō-dīt), a dorsal branch attached to a biramous appendage.

Epithelium (ĕpĭ-thēl'-ĭ-ŭm), a sheet-like group of cells covering an external or internal surface of the body.

Erythrocyte (ē-rĭth'-rō-sīt), red blood corpuscle.

Esophagus (ē-sŏf'-à-gŭs), a tube at the anterior part of the digestive tract.

Estrogen (ĕs'-trō-jen), female hormone secreted by the follicles of the ovaries.

Eustachian (ū-stā'-kĭ-àn), a tube connecting the middle ear to the pharynx.

Evagination (ē-văg-ĭ-nā'-shŭn), an outgrowth from a cavity.

Ex- (ĕx), prefix meaning "out".

Exopodite (ĕx-ŏp'-ō-dīt), the outer branch of a biramous appendage.

Extensor (ĕx-tĕn'-sēr), a muscle that straightens out a joint.

Extracellular (ĕx-trȧ-cĕl'-ū-làr), outside of the cell.

Fascia (făsh'-ĭ-ȧ), a sheet of connective tissue used in binding together and supporting internal body parts such as muscles.

Fauna (fô'-nȧ), the animal life of any region.

Femoral (fĕm'-ō-rȧl), refers to the leg.

Femur (fē'-mûr), the thigh bone; also a segment of insect legs.

Fibula (fĭb'-ū-lȧ), the smaller of the bones of the lower leg.

Fission (fĭsh'-ŭn), the division of an organism into parts of approximately equal size.

Flagellum (flȧ-jĕl'-ŭm), a hair-like projection from certain cells.

Flexor (flĕx'-ēr), a muscle that bends a joint.

Foramen (fōr-ā'-mĕn), an opening in the skull, such as the "foramen magnum" through which the spinal cord passes.

Gamete (găm'-ēt), a sexual reproductive cell which must unite with a gamete of the opposite sex to produce a zygote.

Gametocyte (găm-ēt'-ō-sīt), a cell that is to produce a gamete or gametes; found in the Sporozoa.

Gastrocoel (găs'-trō-sēl), the cavity within the archenteron.

Gastrula (găs'-trū-lȧ), the two-layered stage of the early embryo consisting of ectoderm and endoderm.

Ganglion (găng'-lĭ-ŏn), an enlarged mass of nerve tissue; a nerve center.

Gastrovascular (găs-trō-văs'-cū-làr), a cavity in the body of Coelenterates that serves somewhat for digestion and circulation.

Gene (jēn), an ultramicroscopic unit of heredity.

Genetics (jē-nĕt'-ĭks), a phase of biology dealing with heredity.

Genital (jĕn'-ĭ-tȧl), pertaining to the reproductive system.

Genus (jē'-nŭs), pl. **genera** (jĕn'-ēr-ȧ), a subdivision of biological families; the first word of the scientific name of a plant or animal.

Gizzard (gĭz'-àrd), a part of the digestive tract of certain animals, such as earthworms and birds, where the food is ground by muscular action.

Glochidium (glō-kĭd'-ĭ-ŭm), the larva of fresh-water clams.

Glottis (glŏt'-ĭs), the opening into the larynx.

Goiter (gôi'-tēr), an abnormality of the thyroid gland, sometimes causing a swelling on the neck.

Gonad (gō'-năd), a reproductive gland that produces gametes.

Gracilis (grȧ'-sĭl-ĭs), a muscle on the inner surface of the thigh.

Hemoglobin (hēm-ō-glōb'-ĭn), red, oxygen-absorbing matter found in the blood of many animals.

Hepatic (hē-păt'-ĭk), pertaining to the liver.

Hermaphroditic (hûr-măf'-rō-dīt-ĭc), bearing both male and female sex organs in one body.

Herpetology (hûr-pĕ-tŏl'-ō-jĭ), a study of amphibians and reptiles.

Heterozygous (hĕt-ēr-ō-zīg'-ŭs), bearing unlike genes.

Histology (hĭs-tŏl'-ō-jĭ), a phase of biology dealing with microscopic structure, a subdivision of morphology.

Homologous (hō-mŏl′-ō-gŭs), referring to body parts of animals that have the same embryonic and phylogenetic origin; the parts may be on the same or different animals.

Homology (hō-mŏl′-ō-jĭ), the relationship between body parts having the same embryonic and phylogenetic origin.

Homozygous (hōm-ō-zīg′-ŭs), bearing like genes.

Hormone (hôr′-mōn), a secretion of an endocrine gland that affects vital body reactions in higher animals.

Humerus (hū′-mĕr-ŭs), the bone of the upper part of the arm.

Hyper- (hī′-pĕr), a prefix meaning "over" or "above".

Hypo- (hī′-pō), a prefix meaning "under" or "below".

Hypostome (hī′-pō-stōm), the projection at the oral end of Hydra that bears the mouth on its tip.

Hypothesis (hī-pŏth′-ē-sĭs), an assumption; a scientific possibility used as a basis for scientific investigation.

Hybrid (hī′-brĭd), an individual produced from parents of different genetic constitution.

Ileum (ĭl′-ē-ŭm), the last portion of the small intestine in vertebrates; this comprises the greater part of the small intestine.

Iliac (ĭl′-ĭ-ăk), pertaining to the ilium, a bone of the pelvis.

Ilium (ĭl′-ĭ-ŭm), the anterior bone of the pelvic girdle.

In- (ĭn), prefix meaning "in".

Incisor (ĭn-sīz′-ôr), a front tooth of mammals, designed for cutting.

Ingestion (ĭn-jĕs′-chŭn), the taking in of food by an organism.

Insulin (ĭn′-sū-lĭn), hormone from the pancreas.

Intracellular (ĭn-trȧ-cĕl′-ū-lēr), within the cell.

Invaginate (ĭn-văj′-ĭ-nāt), to fold in, as in the formation of the gastrula.

Ischium (ĭsh′-ĭ-ŭm), the posterior bone of the pelvic girdle.

Jejunum (jē-jū′-nŭm), the middle portion of the small intestine in vertebrates; lies between the duodenum and ileum.

Larva (lär′-vȧ), an active immature stage found in the early postembryonic life of many animals.

Larynx (lăr′-ĭnx), the anterior portion of the tube carrying air to the lungs; contains the vocal cords when they are present.

Leucocyte (lū′-kō-sīt), white blood corpuscle.

Ligament (lĭg′-ȧ-mĕnt), tough, elastic tissue connecting bones at the movable joints.

Littoral (lĭt′-ō-răl), the shallow sea.

Lumbar (lŭm-bär′), pertaining to the region commonly called the "small of the back."

Lumen (lū′-mĕn), the internal cavity of a duct.

Lymph (lĭmf), the portion of the blood that circulates outside of the blood vessels; it contains no red blood corpuscles.

Macronucleus (măk′-rō-nū′-klē-ŭs), the large nucleus found in Paramecium.

Madreporite (măd′-rē-pō-rīt), a small disc on the aboral surface of starfish; it admits water to the water-vascular system.

Mandibular (măn-dĭb′-ū-lȧr), pertaining to the lower jaw.

Manubrium (mȧ-nū′-brĭ-ŭm), an extension down from the umbrella of the jellyfish.

Marine (mȧ-rēn′), pertaining to things associated with the sea; salt water associations rather than fresh water associations.

Maxillary (măx′-ĭ-lăr-ĭ), pertaining to the upper jaw.

Medulla (mě-dŭl′-ȧ), the hind portion of the brain of chordates; the inner portion of the kidney; the inner portion of the adrenal glands.

Medusa (mě-dū′-sȧ), a stage in the life of jellyfish that somewhat resembles an umbrella.

Meiosis (mī-ō′-sĭs), a special type of mitosis in which the chromosome number is halved.

Meroblastic (měr-ō-blăs′-tĭk), refers to an incomplete cleavage of the egg as is found in birds.

Mesenchyme (měs′-ěn-kīm), wandering mesoderm cells.

Meso- (měs′-ō), prefix meaning "middle".

Mesoderm (měs′-ō-dûrm), the middle germ layer of animal bodies.

Mesoglea (měs-ō-glē′-ȧ), a middle jelly-like layer found between the endoderm and ectoderm in the Coelenterata.

Mesonephros (měs-ō-něf′-rŏs), the middle kidney, functional in the adult fish and amphibia.

Metabolism (mě-tăb′-ō-lĭzm), a term referring to the building up of a store of potential energy in the cell and the release of this energy through oxidation.

Meta- (mět′-ȧ), prefix meaning "hind" or "posterior."

Metacarpal (mět-ȧ-cär′-păl), a bone of the hand.

Metamorphosis (mět-ȧ-môr′-fō-sĭs), a transformation from one postembryonic stage to another in the life cycle of certain animals, such as insects.

Metanephros (mět-ȧ-něf′-rŏs), the hind kidney, found in adult reptiles, birds, and mammals.

Metaphase (mět′-ȧ-fāz), the second phase of mitosis.

Metatarsal (mět-ȧ-tär′-săl), a foot bone.

Metazoa (mět′-ȧ-zō-ȧ), animals with many cells in their bodies; animals not in the phylum Protozoa.

Micronucleus (mī′-krō-nū′-klē-ŭs), the small nucleus found in Paramecium.

Mitosis (mī-tō′-sĭs), the process of cell division in which chromosomes are formed and divided within the cell.

Molar (mō′-lär), grinding tooth; jaw tooth of mammals.

Molecule (mŏl′-ē-kūl), the smallest possible unit of matter that retains all of the properties of the matter; a molecule of water contains two atoms of hydrogen and one atom of oxygen and if further divided it loses the properties of water.

Molt (mōlt), a shedding of the outer covering of the body.

Morphology (môr-fŏl′-ō-jĭ), a phase of biology dealing with structure of living organisms.

Morula (môr′-ū-lȧ), a stage of early cleavage of some vertebrates.

Mutation (mū-tā′-shŭn), a change in a gene that produces hereditary modifications in an organism.

Myotome (mī′-ō-tōm), a portion of the somite which develops into the large muscles of the vertebrate body.

Naiad (nā′-ăd), an immature postembryonic stage in the life cycle of insects with incomplete metamorphosis.

Nematocyst (nē-măt'-ō-sĭst), a stinging cell, as found in the Coelenterata.

Nephrotome (nĕ'-frō-tōm), intermediate plate of mesoderm which forms the kidney in embryonic vertebrates.

Neural (nū'-răl), pertaining to the nervous system.

Nephridium (nē-frĭd'-ĭ-ŭm), a small excretory body for collecting and eliminating excretory waste, as found in the earthworm.

Neurocoel (nū-rō-sēl'), the cavity within the spinal cord of chordates.

Notochord (nō'-tō-kôrd), a flexible rod-like body found in all embryonic chordates and in the adult of the more primitive chordates.

Nucleolus (nū-klē'-ō-lŭs), pl. **nucleoli,** a small body in the nucleus which disappears during mitosis.

Nucleoplasm (nū'-klē-ō-plăzm), the clear viscid liquid found in the nucleus.

Nucleus (nū'-klē-ŭs), pl. **nuclei,** a central body in most living cells that directs important activities of the cell and which contains the part of the cell responsible for heredity.

Nymph (nĭmf), an immature postembryonic stage in the life cycle of insects with gradual metamorphosis.

Ocellus (ō-sĕl'-ŭs), pl. **ocelli,** a small simple eye between the compound eyes of arthropods.

Olfactory (ŏl-făk'-tō-rĭ), pertaining to the sense of smell.

Ontogeny (ŏn-tŏj'-ē-nĭ), the development of an individual.

Oocyte (ō-ō-sīt'), a female germ cell during maturation.

Oogenesis (ō-ō-jĕn'-ĭ-sĭs), the events leading up to the formation of an egg.

Ootid (ō-ō-tĭd'), a cell produced by maturation divisions that is to become an egg.

Operculum (ō-pēr'-kū-lŭm), the gill cover of the true fish.

Optic (ŏp'-tĭk), pertaining to the eye.

Oral (ō'-răl), pertaining to the mouth.

Ornithology (ôr-nĭ-thŏl'-ō-jĭ), a study of birds.

Orthogenesis (ôr-thō-jĕn'-ē-sĭs), the theory that animals may overspecialize in certain characteristics due to internal factors.

Osculum (ŏs'-cū-lŭm), an excurrent opening of sponges.

Osmosis (ŏs-mō'-sĭs), the diffusion of a liquid through a differentially permeable membrane.   (See text.)

Ostium (ŏs'-tĭ-ŭm), an opening, such as the anterior opening of the oviduct.

Ovary (ō'-vȧ-rĭ), the female gonad; the gland that produces eggs.

Oviduct (ō'-vĭ-dŭkt), a tube that carries the eggs.

Oviparous (ō-vĭp'-à-rŭs), pertains to animals that lay eggs.

Ovipositor (ō-vĭ-pŏs'-ĭ-tēr), egg-depositing structure found in many insects.

Ovoviviparous (ō-vō-vĭ-vĭp'-à-rŭs), young born alive through hatching of the eggs before laying; there is no placenta.

Oxidation (ŏx-ĭ-dä'-shŭn), the chemical combination of oxygen with some other substance.

Paleontology (pāl-ē-ŏn-tŏl'-ō-jĭ), a phase of biology dealing with a study of life as it existed in the past.

Palp (pălp), a small projection such as is found on either side of the mouth in clams.

Pancreas (păn'-krē-ŭs), a gland found in the loop of the duodenum; secretes pancreatic juice and insulin.

Parasite (păr'-à-sīt), a living thing that lives in close association with some other living thing, deriving its nourishment from its host, but not contributing anything to the welfare of the host.

Parasitism (păr'-à-sīt-ĭzm), an association between two living organisms in which one benefits and the other is harmed by the association.

Pathogenic (păth-ō-jĕn'-ĭk), disease producing.

Pectoral (pĕk'-tō-ràl), pertaining to chest.

Pedal (pĕd'-àl), pertaining to the feet.

Pedicellaria (pĕd-ĭ-sĕ-lā'-rĭ-à), small pinchers found on the surface of many echinoderms.

Pedipalp (pĕd'-ĭ-pălp), a small, leg-like appendage near the mouth of spiders.

Pelagic (pē-lăj'-ĭk), pertaining to the open sea.

Pellicle (pĕl'-ĭ-kl), the outer covering of certain protozoa, such as Paramecium.

Pelvic (pĕl'-vĭk), refers to the hip region.

Penis (pēn'-ĭs), a male reproductive organ used to transfer sperm to the body of the female.

Peri- (pĕr'-ĭ), prefix meaning "around".

Perimysium (pĕr-ĭ-mĭ'-shĭ-ŭm), a tough transparent membrane surrounding a muscle, holding the fibers together.

Peristaltic (pĕr-ĭ-stăl'-tĭk), referring to the method of movement of materials through the alimentary tract and of the blood through vessels in annelid worms.

Peritoneum (pĕr-ĭ-tō-nē'-ŭm), tissue that lines the coelom.

Phalanges (fă-lăn'-jēs), finger bones and toe bones.

Pharynx (făr'-ĭngks), a cavity connected to the mouth, usually just posterior to the mouth.

Phylogeny (fī-lŏj'-ē-nĭ), the development of the race.

Phylum (fī'-lŭm), pl. **phyla,** a major division of the plant or animal kingdoms.

Physiology (fĭz-ĭ-ŏl'-ō-jĭ), a phase of biology dealing with the functioning of the living organism.

Pituitary (pĭ-tū'-ĭ-tār-ĭ), an endocrine gland found in the head.

Pituitrin (pĭ-tū'-ĭ-trĭn), hormone produced by the posterior lobe of the pituitary gland.

Placenta (plă-sĕn'-tà), an outgrowth of the embryonic mammal that forms an intimate attachment with the uterus of the mother and through which food, oxygen, and wastes are exchanged.

Plankton (plăngk'-tŏn), small organisms on the surface of bodies of water.

Plasma (plăz'-mà), the liquid part of the blood or lymph.

Plasma membrane, the thin differentially permeable membrane that surrounds the protoplasm of a cell, regulating the movements of materials into and out of the cell.

Polyp (pŏl'-ĭp), a stage in the life of coelenterates that somewhat resembles Hydra and is attached so that it cannot move from place to place.

Post- (pōst), prefix meaning "behind".

Pre- (prē), prefix meaning "in front of".

Predaceous (prē-dā'-shŭs), animals which feed or prey on other animals.

Pro- (prō), prefix meaning "first" or "before".

Proboscis (prō-bŏs'-ĭs), an extension of the nose or mouth parts; may be the nose, as in the elephant; the mouth, as in sucking insects; or the pharynx, as in Planaria.

Proctodeum (prōk'-tō-dē-ŭm), embryonic invagination that forms the anus.

Progesterone (prō-jĕs'-tĕr-ōn), female hormone secreted by the corpus luteum.

Progestin (prō-jĕs'-tĭn), hormone secreted by the corpora lutea.

Proglottid (prō-glŏt'-tĭd), a segment of a tapeworm's body.

Prophase (prō'-fāz), the first phase of mitosis.

Protoplasm (prō'-tō-plăzm), the living matter within the cell.

Protopodite (prō-tŏp'-ō-dīt), the portion of a biramous appendage that is attached to the crustacean.

Pseudocoel (sū'-dō-sēl), false body cavity as found in the roundworms.

Pseudopodium (sū-dō-pōd'-ĭ-ōm), a temporary appendage thrust out by certain cells for the purpose of locomotion or feeding; found in Amebae and white blood cells.

Pubis (pūb'-ĭs), the anterior bone of the pelvic girdle.

Pulmonary (pŭl'-mō-nēr-ĭ), pertaining to the lungs.

Pupa (pū'-pà), the inactive stage which follows the larval stage in insects having a complete metamorphosis.

Pyloric (pī-lō'-rĭk), refers to the region where the stomach connects with the intestine.

Pylorus (pī-lō'-rŭs), the opening between the stomach and the small intestine.

Radius (rā'-dĭ-ŭs), the shorter bone of the forearm.

Regeneration (rē-jĕn-ēr-ā'-shŭn), the replacement of lost or injured parts by animals.

Renal (rē'-nàl), refers to the kidney.

Retina (rĕt'-ĭ-nà), the inner light sensitive layer of the eye.

Ruminant (rū'-mĭn-ànt), an ungulate that chews a cud.

Sacral (sā'-kràl), pertaining to the region where the pelvic girdle and the vertebrae come together.

Sartorius (sär-tō'-rĭ-ŭs), a leg muscle on the inner surface of the thigh.

Scapula (skăp'-ū-là), the shoulder blade.

Schizocoel (skĭz'-ō-sēl), a cavity arising by the splitting of a layer of mesoderm.

Sclerotome (sklĕr'-ō-tōm), the inner portion of the somite which forms the vertebrae of vertebrates.

Sclera (sklēr'-à), the outer, white layer of the eye.

Scolex (skō'-lĕx), the "head" of a tapeworm.

Scrotum (skrō'-tŭm), the sac in which the testes are suspended.

Semen (sē'-mĕn), sperm together with the fluid in which they are suspended for ejaculation; the spermatic fluid.

Semimembranosus (sĕm-ĭ-mĕm'-brà-nō-sŭs), a large muscle found on the outer surface of the thigh.

Seminal (sĕm'-ĭ-nàl), pertaining to semen.

Septum sĕp'-tŭm), p. **septa**, an internal body partition.

Sinus (sī'-nŭs), a cavity.

Somite (sō-mīt'), regularly arranged muscle segments, as found in embryonic chordates.

Species (spē'-shēs), pl. **species**, a subdivision of genera; the second word of the scientific name of a plant or animal.

Spermatid (spûr-mà-tĭd'), a cell produced by maturation divisions that is to become a sperm.

Spermatocyte (spûr'-mà-tō-sīt), a male germ cell during maturation.

Spermatogenesis (spûr-mă-tō-jĕn'-ē-sĭs), the events leading up to the formation of sperm.

Sphincter (sfĭngk'-tēr), a muscular band that closes a tube, such as the digestive tract.

Spicules (spĭk'-ūls), spiny structures embedded in the bodies of most sponges.

Spinneret (spĭn-ēr-ĕt'), web-spinning structure found on the ventral surface of spiders.

Spiracle (spīr'-à-kl), body opening associated with respiration, found in insects and elasmobranchs.

Spleen (splēn), a gland found near the posterior portion of the stomach.

Sternum (stûr'-nŭm), the breast bone.

Stomodeum (stō-mō-dē'-ŭm), embryonic invagination that forms the mouth.

Strand (strănd), the area between high and low tide marks.

Striated (strī'-āt-ĕd), bearing striations, used in referring to muscle fibers bearing delicate cross and longitudinal lines.

Suture (sū'-tūr), the point of junction of bones at an immovable joint; to sew together.

Symbiosis (sĭm-bĭ-ō'-sĭs), the association of two living organisms for their mutual benefit.

Synovial (sĭn-ō-vī-àl), referring to movable bone joints.

Syrinx (sĭr'-ĭnx), an enlargement of the trachea of birds; the sound producing apparatus.

Systemic (sĭs-tĕm'-ĭk), pertaining to the body generally.

Tarsal (tär'-sàl), an ankle bone.

Tarsus (tär'-sŭs), the ankle bones of vertebrates; the distal segments of the legs of insects.

Taxonomy (tăx-ŏn'-ō-mĭ), a phase of biology dealing with classification of living organisms.

Telophase (tĕl'-ō-fāz or tē'-lō-fāz), the last stage of mitosis.

Telson (tĕl'-sŭn), the fan-shaped structure on the posterior end of crayfish and lobsters.

Tendon (tĕn'-dŭn), a tough, elastic fiber connecting a muscle to a bone.

Testosterone (tĕst-ŏs'-tēr-ōn), male hormone secreted by the testes.

Testis (tĕs'-tĭs), pl. **testes,** the male gonad; the gland that produces sperm.

Theory (thē'-ō-rĭ), a scientific assumption, usually considered to have more weight of evidence supporting it than an hypothesis.

Thoracic (thō-răs'-ĭk), pertaining to the chest.

Thorax (thō'-răx), the chest region of an animal body.

Thrombocyte (thrŏm'-bō-sīt), blood platelet.

Thyroxin (thī-rŏx'-ĭn), the hormone produced by the thyroid gland.

Tibia (tĭb'-ĭ-à), the larger of the bones of the lower leg; also a segment of insect legs.

Tissue (tĭs'-sū), a group of similar cells together with the intercellular matrix that surrounds them.

Trachea (trā'-kē-à), the tube carrying air from the larynx to the branchial tubes in most air-breathing vertebrates.

Trichocyst (trĭ'-kō-sĭst), tiny bulbs of a gelatinous liquid that may be expelled to form sticky threads in certain protozoa.

Triploblastic (trĭp-lō-blăs'-tĭk), having three germ layers in the body.

Tympanic (tĭm-păn′-ĭk), refers to the cavity of the middle ear.

Typhlosole (tĭf′-lō-sōl), a dorsal fold of the intestine, as found in the earthworm.

Ulna (ŭl′-nà), the longer bone of the forearm.

Umbilical (ŭm-bĭl′-ĭ-kàl), pertaining to the umbilicus; the region where the embryo forms a connection to the embryonic membranes.

Umbo (ŭm′-bō), a hump found on bivalved mollusk shells near the hinge.

Ureter (ū-rē′-tēr), an excretory tube leading from the kidney to the bladder.

Urethra (ū-rē′-thrà), tube leading from the bladder to an external urinary opening.

Urogenital (ū-rō-jĕn′-ĭ-tàl), pertaining to both excretory and reproductive systems.

Urostyle (ūr-ō-stīl′), the posterior portion of the vertebral column of the frog, formed by fusion of caudal vertebra.

Vacuole (văk′-ū-ōl), a vesicle of non-living liquid material within the cell.

Vagina (vă-jī′-nà), the cavity between the uterus and the external genital opening of the female of many animals.

Vas deferens (väs dĕf′-ēr-ĕns), pl. **vasa deferentia** (väs′-à dĕf-ēr-ĕn′-tĭ-à), tubes that carry the sperm in the male reproductive system.

Vas efferens (väs ĕf′-fēr-ĕns), pl. **vasa efferentia** (väs′-à ĕf-ēr-ĕn′-tĭ-à), small tubules that collect the sperm from the testes and transfer them to the vas deferens.

Velum (vēl′-ŭm), a membrane found on the subumbrella surface of some jellyfish.

Ventricle (vĕn′-trĭ-kl), a chamber of the heart that pumps blood from the heart.

Vertebra (vēr′-tē-brà), a bone of the vertebral column.

Visceral (vĭs′-ēr-ăl), referring to the internal organs.

Viviparous (vī-vĭp′-à-rŭs), placental, live-bearing reproduction.

Zoogeography (zō-ō-gē-ŏg′-rà-fĭ), a study of animal distribution.

Zoology (zō-ŏl′-ō-jĭ), the science dealing with animal life.

Zygote (zī′-gōt), a cell formed by the union of gametes of opposite sexes.

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